U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-263 504

Electrostatic Precipitator Malfunctions in the Electric Utility Industry

PEDCo-Environmental Specialists, Inc Cincinnati, Ohio

Prepared for

Industrial Environmental Research Lab, Research Triangle Park, N C

Jan 77

PB 263 504

EPA-600/2-77-006
JANUARY 1977

Environmental Protection Technology Series

UNITED STATES · ENVIRONMENTAL PROTECTION AGENCY

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-006	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Electrostatic Precipitator Malfunctions in the Electric Utility Industry		5. REPORT DATE January 1977
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Mike Szabo and Richard Gerstle		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS PEDCo.-Environmental Specialists, Inc. Atkinson Square, Suite 13 Cincinnati, Ohio 45246		10. PROGRAM ELEMENT NO. 1AB012; ROAP 21BAV-018
		11. CONTRACT/GRANT NO. 68-02-2105
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development - RTP, NC Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 9/75-8/76
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer for this report is D. C. Drehmel, 919/549-8411 Ext 2925, Mail Drop 61.

16. ABSTRACT The report discusses precipitation malfunctions in the electric utility industry. When a utility electrostatic precipitator (ESP) fails to achieve its design efficiency, there must be a reason. Although the reasons are numerous, they can be placed in two distinct categories: ESP degradation is attributable either to hardware malfunctions or operation under improper conditions. The report discusses the various types of ESPs in the electric utility industry, along with design considerations. It summarizes the different types of malfunctions. For each type of malfunction, it gives the cause, duration, corrective action, and preventive measures. The report also gives the maintenance required to minimize the probability of malfunction. It describes inspection techniques for evaluating maintenance procedures, including what an inspector should look for during power plant ESP inspections.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Maintenance	Air Pollution Control	13B	15E
Electrostatic Precipitators		Stationary Sources		
Failure	Inspection	Particulate	14D	
Electric Utilities				
Flue Gases			21B	
Dust			11G	

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 143
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE 6.00 - 3.00

EPA Form 2220-1 (9-73)

EPA-600/2-77-006
January 1977

ELECTROSTATIC PRECIPITATOR MALFUNCTIONS IN THE ELECTRIC UTILITY INDUSTRY

by

Mike Szabo and Richard Gerstle

PEDCo.-Environmental Specialists, Inc.
Atkinson Square, Suite 13
Cincinnati, Ohio 45246

Contract No. 68-02-2105
ROAP No. 21BAV-081
Program Element No. 1AB012

EPA Project Officer: Dennis C. Drehmel

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

ACKNOWLEDGEMENT

This report was prepared for the U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina, by PEDCo-Environmental Specialists, Inc., Cincinnati, Ohio. The project director was Mr. Richard W. Gerstle and the project officer was Mr. Norman J. Kulujian. Principal investigators were Messrs. Norman J. Kulujian and Lario V. Yerino. The principal authors of the report were Messrs. Michael F. Szabo and Richard W. Gerstle. Editorial review was provided by Ms. Anne Cassel. Graphics were prepared under the direction of Ms. Nancy Wohleber.

Dr. Dennis Drehmel was the project officer for the U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina. The author appreciates the assistance and cooperation provided by Dr. Drehmel, and the other utilities and precipitator manufacturers, who wish to remain anonymous but contributed information to this project.

ABSTRACT

A comparison of the advantages and disadvantages of hot and cold precipitators is followed by a discussion of design considerations that apply to hot and cold precipitators. Common malfunctions found with precipitators operating on coal-fired boilers in the electric utility industry and corrective or preventive measures are summarized. A precipitator operation and maintenance procedure for minimizing malfunctions and downtime is presented, procedures followed by utilities during startups and malfunctions are described, and costs of precipitator maintenance are discussed. Procedures for inspection of a precipitator at a utility operating a coal-fired boiler are outlined. Appendices compare precipitator operation and maintenance guidelines recommended by precipitator manufacturers versus the utility which operates the precipitator; an operating history of precipitators at a major utility is also presented.

TABLE OF CONTENTS

Page

ACKNOWLEDGMENT ii

ABSTRACT iii

1.0 INTRODUCTION 1-1

2.0 TYPES OF ELECTROSTATIC PRECIPITATOR (ESP) SYSTEMS 2-1

2.1 Cold-side and Hot-side ESP's 2-1

2.2 Design Considerations for Major ESP Components 2-4

3.0 MALFUNCTIONS 3-1

3.1 Types of ESP Malfunctions 3-1

3.2 Conditions Specific to Power Plants that Cause Problems in Precipitators 3-16

3.3 Reduced ESP Collection Efficiency as Related to Number of Bus Sections Not in Operation 3-24

3.4 Maintainability of ESP Equipment as Related to Frequency of Malfunctions 3-26

4.0 MAINTENANCE 4-1

4.1 Maintenance Program for Precipitators 4-1

4.2 Utility Procedures and Recordkeeping During Startup and Malfunctions 4-19

4.3 Costs of Cold Side ESP Maintenance and Operation 4-23

Preceding page blank

TABLE OF CONTENTS (continued).

Page

5.0 INSPECTION TECHNIQUES FOR EVALUATING MAINTENANCE PROCEDURES 5-1

- 5.1 Typical ESP Inspection Procedure 5-1
- 5.2 Inspection Checklist for Electrostatic Precipitators in the Electric Utility Industry 5-11

APPENDIX A ESP MANUFACTURERS SUGGESTED MAINTENANCE PROCEDURES A-1

APPENDIX B UTILITY ESP MAINTENANCE PROCEDURES B-1

APPENDIX C EXAMPLE OPERATING HISTORY OF COLD-TYPE PRECIPITATORS C-1

LIST OF FIGURES

No.		Page
2-1	ESP Particle Charging System and Wire Hanging System	2-8
2-2	ESP Plate Hanging System	2-9
2-3	Cutaway View of a Typical ESP and Arrangement of Field and Cells	2-16
3-1	Shrouds for Wire-weighted Discharge Electrodes	3-7
3-2	Typical Sparking Levels When Precipitating Dusts with Different Resistivities	3-19
3-3	Typical Operating Curve to Meet Emission Regulations with Partial Malfunctions of ESP	3-25
5-1	Electrostatic Precipitator Collection Efficiency vs. Delivered Power	5-8
5-2	Cold-side ESP. SCA vs. % S	5-10

LIST OF TABLES

No.		Page
3-1	Summary of Problems Associated with ESP's	3-2
4-1	Maintenance Items for Electrostatic Precipitators	4-2
4-2	Troubleshooting Chart for ESP's	4-15
4-3	Summary of Characteristics and Assumption For Model Plants	4-26
4-4	Coal Analyses Assumed for ESP Cost Evaluation	4-28
4-5	Capital Costs for Electrostatic Precipitators	4-29
4-6	Annualized Costs for Electrostatic Precipitators	4-31
5-1	Plume Characteristics and Operating Parameters for Coal-fired Boilers	5-2
5-2	Recommended Recordkeeping Requirements	5-6

1.0 INTRODUCTION

When an electrostatic precipitator installed on a utility boiler fails to achieve design efficiency, operators must determine the causes for poor performance. Although the reasons for poor performance are numerous, they can be grouped in two distinct categories: degradation of ESP efficiency is attributable either to hardware malfunctions or to improper operation. The purpose of this report is to examine precipitation malfunctions in the electric utility industry. Under EPA sponsorship PEDCo-Environmental Specialists has prepared concurrently another document discussing electrostatic precipitator performance related to operational and maintenance practices.

It is assumed that the reader has a working knowledge of electrostatic precipitators. The various types of precipitators in the electric utility industry are discussed in Section 2.0, along with design considerations. Major types of malfunctions are summarized in Section 3.0. For each type of malfunction, the possible cause, duration, corrective action, and preventive measures are stated. Section 4.0 presents the maintenance procedures that can minimize the probability of malfunctions occurring. Section 5.0

describes inspection techniques for evaluating ESP maintenance procedures and describes in detail the items to be checked during inspection of power plant precipitators.

Appendix A presents a typical precipitator manufacturer's recommended operation and maintenance procedure; Appendix B is an example of a concientious utility precipitator operation and maintenance schedule. The precipitator operating history of a major U.S. utility is summarized in Appendix C.

2.0 TYPES OF ELECTROSTATIC PRECIPITATOR (ESP) SYSTEMS

This section discusses the various types of electrostatic precipitators, presenting a detailed discussion of the major ESP components. It is assumed that the reader understands the fundamentals of ESP operation and theory, which are described in many references.[1,2,3]

2.1 COLD-SIDE AND HOT-SIDE ESP'S[3,4,5]

The two categories of ESP's for use with coal-fired boilers are based in location relative to the air preheater and thus are temperature-dependent. The cold-side ESP, currently predominant in the utility industry, is located downstream of the air preheater, operating in the temperature range of 200 to 400°F. It is used mostly with high-sulfur coals, since the high resistivity associated with most low-sulfur coal in the operating temperature range would require larger plate areas in cold-side ESP's.

The hot-side ESP is located upstream of the air preheater and operates at temperatures above 230°C (450°F). The gas flow upstream of the air preheater at 371°C (700°F) is about 1.5 times the volume of air downstream of the air preheater; a relatively larger ESP is usually required to handle gases at the higher temperature. With many low-sulfur coals, however, because of their high resistivity in the 93 to 204°C (200 to 400°F) range, it is the smaller gas volume that requires the larger ESP. The greatest advantage of the hot-side ESP over the cold-side ESP, is its constant efficiency under varying fuel conditions. Changes in the fuel fired in a boiler are necessitated by such things as contract variances, price differentials, and availability. Since the hot-side precipitator is located ahead of the air preheaters, it operates at the temperatures of the boiler flue gas exhaust, and the fly ash resistivity is reduced to levels that allow better precipitation. At this higher temperature resistivity is not sensitive to the fuel's sulfur content.

Since hot-side ESP is located on the hot gas side of the air preheater, the fouling of heat transfer surfaces by ash should be eliminated, the plant should operate more efficiently, and requirements for soot blowing from the air preheater should be reduced.[4] Use of high-sulfur coal might introduce a detrimental factor, since the fly ash often acts to remove any sulfur trioxide present in the gas stream and, if the particulate is removed ahead of the air preheater, there is a potential for corrosive attack in the preheater.

The typical hot-side precipitator operates at relatively lower voltages, but, if properly designed, it operates at much higher current densities; it is characterized by relatively high power density, and by stable, current-limited operation, with sparking usually confined to inlet sections where dust concentrations are high.

The cold-side ESP does not undergo the thermal expansion associated with a pronounced temperature increase, as does the hot-side ESP. The expansion can result in extreme misalignment or even duct discontinuities. Such failures have been traced to inadequate provision for differential thermal expansion between the lower shell and support structure, and between the precipitator shell and roof housing. These problems can be minimized with provisions for differential movement of the precipitator on its support structure, proper insulation, and adherence to design stresses, particularly in regions where temperature gradients cannot be avoided.

Some ESP manufacturers favor cold-side installations, whereas others stress hot-side units; there is no clear-cut, all-inclusive criteria for choice of either type.[3,4] The selection is usually based on operability and economics. In general, for new construction, if the cold-side unit requires a specific collection electrode area (SCA) greater than 500 to 600 square feet per thousand cubic feet of gas flow per minute, then a hot-side unit would be the proper choice. If the SCA can be smaller, a cold-side unit could be used.

The situation is somewhat more complicated in retrofit installations. A hot-side unit requires addition of ductwork to transport the gas stream from the air preheater inlet to the ESP and back to the air preheater. The considerable expense that can be involved tends to swing the economics toward a cold-side installation for retrofit systems.

With respect to a specific installation the following guidelines for selection are suggested:

(1) Determine resistivity as a function of temperature.

(2) Evaluate severity of the potential resistivity problem considering consistency of coal supplies and variation in coal characteristics.

(3) Conduct comparative cost estimates with emphasis on retrofit difficulty.

Neither type of ESP installation can provide perfect service. Each requires regular attention to ensure good service and to minimize malfunctions.

2.2 DESIGN CONSIDERATIONS FOR MAJOR ESP COMPONENTS[6]

2.2.1 Rapping Systems

Rappers are incorporated in the ESP to remove dust from the collecting and discharge surfaces; effectiveness and reliability of the rappers are essential. The following types are generally available:

- Electromagnetic impulse, either single or multiple
- Electric vibrators
- Pneumatic impulse
- Various mechanical hammers, usually associated with foreign designs, but sometimes furnished by others for special applications.

Each ESP manufacturer develops rapper designs for compatibility with his suspension system and rapper schedule (number of surfaces per rapper), based on experience and tests. Generally, pneumatic rappers impart more energy than either electromagnetic rappers or electric vibrators and remove tenacious dusts more readily. It is important, however, to be certain that all hardware in the system is designed to withstand such high energy forces. Changing from electrical to pneumatic rappers in an attempt to improve operation without also strengthening the hardware has led to structural failure.

Current designs for horizontal rapping hammers impart more energy to the plates than do conventional designs; these rappers remove fly ash from the plates in a very efficient manner.

Mechanical hammers also are often very effective, but moving parts in a dirty gas stream require frequent maintenance. Repairs require shutdown of an entire chamber or system.

The number and size of rappers required for a particular installation vary with precipitator manufacturer and nature of the dust. Requirements for collecting surface area range from 110 to 550 m^2 (1200 to 6000 square feet) per rapper. Discharge electrode rappers serve from 1000 to 7000 feet of wire per rapper. Rapper intensity ranges from about 35 to 70 J (25 to 50 foot-pounds) per cycle. Rapping intervals are adjustable over a range of approximately 30 to 600 seconds between raps.

The paramount consideration in rapping is to provide ample acceleration to dislodge the dust without excessive reentrainment. Accelerations of 30 to 50 g per rap, as measured on the collection electrode, are required for removal of fly ash. Both cycle and rapping intensity are usually adjusted in the field to optimize rapping operations for maximum precipitator performance.

2.2.2 Wire and Plate Hanging Mechanisms

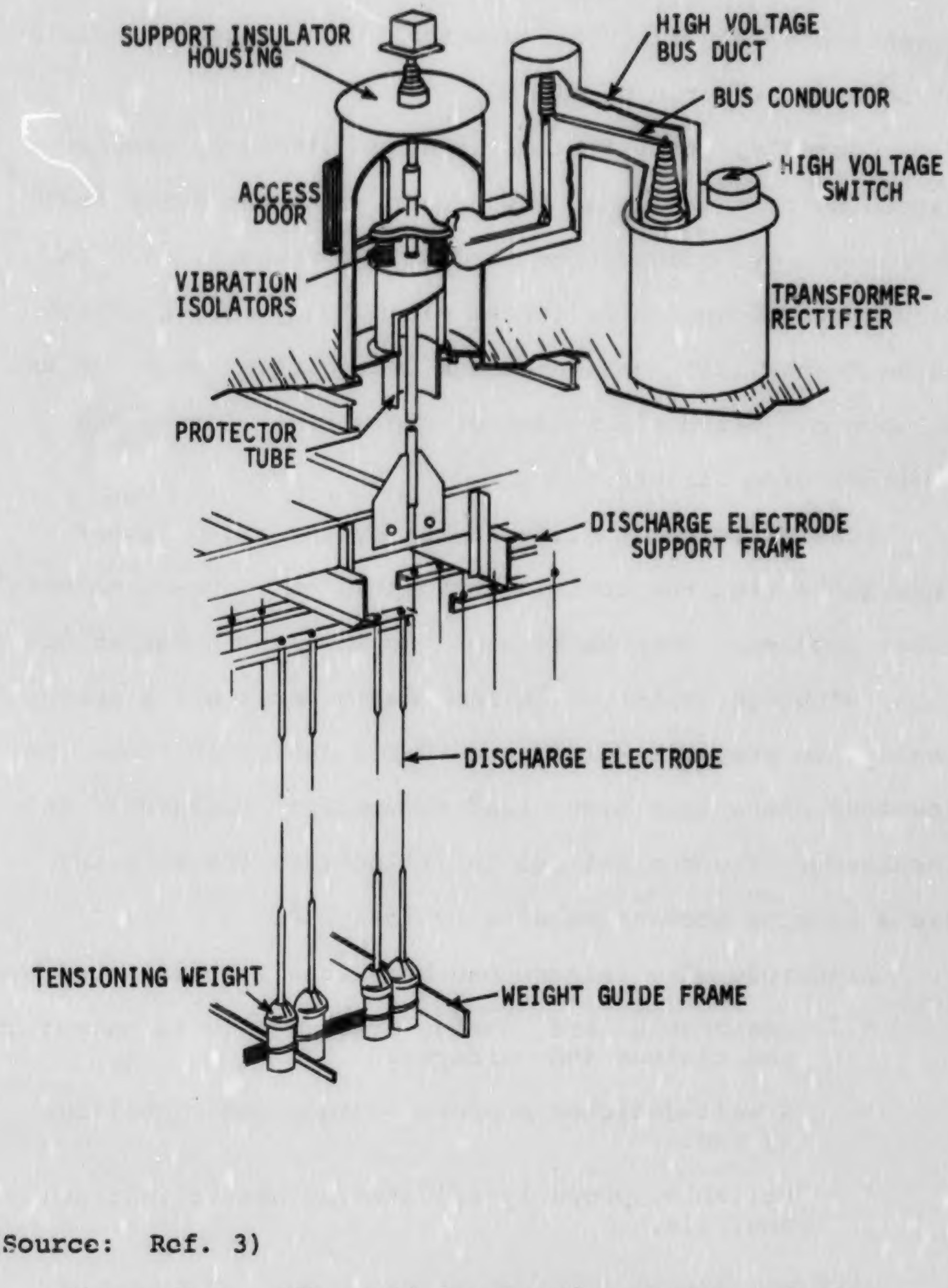
2.2.2.1 Wire Weight System - The wire weight system consists of individual electrode wires suspended from an upper support frame. The wires are best shrouded in some fashion to prevent arcing to the exposed, sharp ground edges, or where the electrical clearance is reduced by passing the tops and bottoms of the collecting dust plates. The wires are held taut by weights suspended from their bottoms. The weights in turn are spaced by a guide frame. The frame must be stabilized against swinging, an action that may be generated mechanically by the gas stream, by "electrical wind," by an improperly functioning automatic voltage-control, or by some combination of these.

Commonly, stabilization is accomplished by trusses extending from the upper support frame to the guide frame. Rapper energy, transmitted through the trusses, aids in keeping the lower guide frames clean. Any design of the guide frames that permits enough dust buildup to raise the weights may cause slackening of the wires, arcing, and eventual wire failure.

Stabilization of guide frames by ceramic or other insulators from the casings or hoppers can cause a maintenance problem. Dust buildup on the insulators during operation, although resistive in some cases, presents a source of leakage to ground. Moisture gathered during shutdown (or low-load operation) might lead to complete failure of an insulator. Figures 2-1 and 2-2 illustrate the wire and plate hanging mechanisms of a typical ESP.

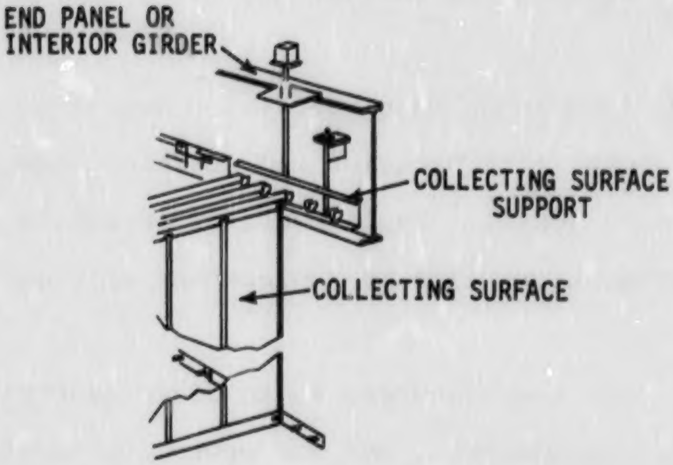
Electrode wire failure can be virtually eliminated by:

- Reasonable care, during erection, in alignment of the casings and surfaces.
- A well-designed support, guide, and stabilizer system.
- Reliable, properly adjusted automatic voltage-controls.


SUPPORT INSULATOR HOUSING
HIGH VOLTAGE BUS DUCT
BUS CONDUCTOR
HIGH VOLTAGE SWITCH
ACCESS DOOR
VIBRATION ISOLATORS
TRANSFORMER-RECTIFIER
PROTECTOR TUBE
DISCHARGE ELECTRODE SUPPORT FRAME
DISCHARGE ELECTRODE
TENSIONING WEIGHT
WEIGHT GUIDE FRAME

(Source: Ref. 3)

Figure 2-1. ESP particle charging system and wire hanging system.


END PANEL OR
INTERIOR GIRDER
COLLECTING SURFACE
SUPPORT
COLLECTING SURFACE

(Source: Ref. 3)

Figure 2-2. ESP plate hanging system.

- Good operating maintenance of the dust-handling system.

2.2.2.2 Rigid Wire Frame - The rigid wire frame design was furnished by U.S. suppliers prior to 1950 and then was abandoned (in favor of the wire-weight design) because of reliability and operating problems. Recently U.S. licensees of foreign manufacturers have reintroduced frame electrodes to this country; installations are now in operation and on order (as wire-weight designs are being installed in European plants).

The rigid frame requires a high degree of quality control, both in fabrication and erection, and is intrinsically more costly. Replacement or repair is expensive and time-consuming, similar to replacement of a dust-collecting plate.

At lower temperatures, up to 204°C (400°F), warpage of the frames is uncommon, but for operating temperatures above 204°C (400°F), or with cyclical operation, potential deformation of the frames becomes serious.

The rigid frame entails wider gas lanes, or ducts, to provide electrical clearance between the frame and the dust-collecting plate. This requirement leads to larger casings to house the required surface areas.

It is important that the engineer be fully aware of the differences and the requirements of each design philosophy in detail, so that he avoids incorrect evaluations of one versus another.

The erection sequence usually consists of casings and hoppers first, followed by collecting surfaces and then discharge systems. If the casings are not erected to true dimensions, plumbed vertically, and square cornered in the plan view, attempts are often made to compensate during installation of collecting surfaces, i.e., using guides that should be free of frictional loads as "jacks," and so forth. Then, the discharge system, which should hang freely, is stabilized in an offset position to maintain, as best possible, the wire-to-plate centers. Such a construction will probably involve difficulties from the first day of operation. There is great need, therefore, to provide step-by-step quality control and inspection of the installation, regardless of the pressure of construction schedules.

Discharge systems are supported from the casing through standoff electrical insulators. These must be kept clean and dry during operation to prevent accumulation of dust or moisture coatings, which provide a path for leakage to ground. Wet accumulations are common during shutdown, as the moisture in the gas condenses. They can be prevented by provision of warmed, filtered pressurizing-air supplies.

The system must provide distribution to a multiplicity of insulators, none of which may be allowed to "starve" because of disproportionate flow. This design problem is similar to that of balancing an air-conditioning system. Some method for checking distribution should be provided to the operators. Maintenance routines for changing filters and checking heater elements should be established as soon as the system is operational.

Most of the commonly used electrical insulators lose dielectric strength as temperature increases. Although the maximum temperature varies with the insulating material, 204°C (400°F) is a probable limit. Therefore, the electrical insulators must be isolated thermally from hot gases. The purge air system normally suffices, but insulators mounted on hot steel casing may be affected by conduction, at least for several inches along the length. Fortunately, most electric insulators retain structural strength under higher temperatures, and also act somewhat as thermal insulators so that if the electrical path is long enough, the effect of the conducted heat is limited to a short distance up the insulator.

2.2.3 Aspect Ratio

An important variable in precipitator design is the aspect ratio (ratio of length to height of gas passage). Space requirements often determine the overall precipitator dimensions. Wherever possible, the engineer should select an aspect ratio that will result in ample opportunity for reentrained dust from the first sections to be recollected. The aspect ratio is integrally related to the overall design of the precipitator, and also depends on such variables as gas velocity m^3/min (acfm), total plate collection area m^2 (ft^2), specific collecting area [m^2/1000 m^3/min (ft^2/1000 acfm)], and power density [watts/m^2 (watts/ft^2) of collecting plate]. All other factors being equal, higher ratios of length to height provide better performances. Historically this value varies between 0.5 and 1.5 with a present day average of 0.3. Plate heights usually range from 7 to 14 m (24 to 45 ft).

Precipitator collection plates are made in standardized size ranges, typically 7-9-11 m (24-30-36 ft) height by 0.9-1.2 m (3-4 ft) length. Once the collection area is selected, the design will incorporate enough collecting-plate sections to yield the required surface area.

Plate area requirements are governed primarily by the properties of the dust and gas and the desired dust collection efficiency. Efficiency is related to the collection plate area and gas volume by the relationship

$$n = 1 - e^{-}\left(\frac{A}{V} w\right)$$

which is the conventional Deutsch-Anderson equation, where A is the plate area, V the gas flow, and w the precipitation rate parameter of migration velocity. A serious limitation in use of the Deutsch-Anderson equation is that the particle size distribution and, subsequently, the effective migration velocity change as precipitation proceeds. The Deutsch-Anderson equation does not account for this change.

A recent empirical modification of the equation by Matts and Öhnfeldt[7] essentially removes the size dependence on w. The equation is: $n = 1 - \exp(-w_k A/Q)^k$ where k is said to be equal to about 0.5 in most cases. This equation is an improvement over the Deutsch-Anderson equation because w_k can be treated as a constant in any given application.

2.2.4 Field/Bus Section/TR Set Breakups

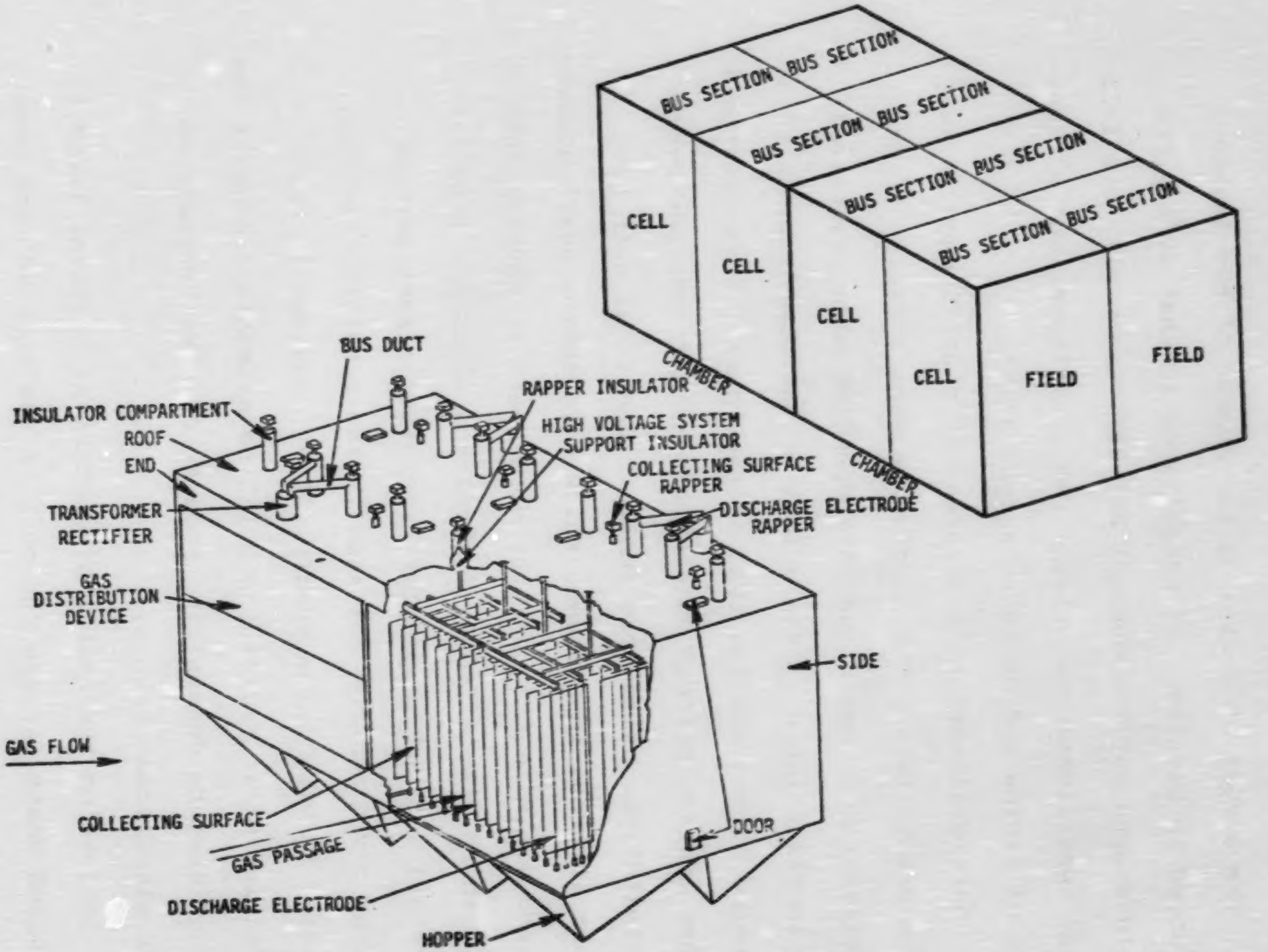
The electrical system of an ESP is arranged in bus sections, each bus section representing any portion of the ESP that can be energized independently. This is done by subdividing the high-voltage system and arrangement of the support insulators.

The number of fields, which is the number of bus sections arranged in the direction of gas flow, is calculated as follows: as a rule of thumb, manufacturers use one field for up to 90 percent collection efficiency, two fields for up to 97 percent, three fields for up to 99 percent, and four or more fields for efficiencies above 99 percent.

The number of cells, or the number of bus sections arranged in parallel, is established so that if any one field shorts out the overall ESP efficiency will not fall below specifications. Figure 2-3 illustrates the arrangement of fields and cells in a typical ESP.

Sectionalization is of greatest significance in very large precipitators for several reasons. First, if the precipitator is operating in a sparking mode, increased sectionalization will cause less of the precipitator to be disabled during the interval of the spark. This results in higher average voltage, higher electric field, and better precipitation. Also, the smaller electrical sets have higher internal impedances, which give better spark quenching and minimize the tendency of a spark to develop into an arc. Third, the effects of localized electrode misalignments are limited to smaller precipitator sections and thereby permit higher voltages in the remaining sections. Finally, in very large precipitators, reasonably good collection efficiencies can still be maintained even if one section must be deenergized because of wire breakage or other electrical trouble.

Increasing the number of electrical sections leads to increased costs because the cost of the high-voltage power supply is not linearly related to power handling capability.


BUS SECTION
BUS SECTION
BUS SECTION
BUS SECTION
BUS SECTION
BUS SECTION
BUS SECTION
BUS SECTION
CELL
CELL
CELL
CELL
FIELD
FIELD
CHAMBER
CHAMBER
BUS DUCT
RAPPER INSULATOR
INSULATOR COMPARTMENT
ROOF
END
HIGH VOLTAGE SYSTEM SUPPORT INSULATOR
COLLECTING SURFACE RAPPER
DISCHARGE ELECTRODE RAPPER
TRANSFORMER RECTIFIER
GAS DISTRIBUTION DEVICE
SIDE
GAS FLOW
COLLECTING SURFACE
GAS PASSAGE
DOOR
DISCHARGE ELECTRODE
HOPPER

(Source: Ref. 8)

Figure 2-3. Cutaway view of a typical ESP and arrangement of field and cells.

The greater portion of the cost is in providing the high-voltage equipment. Increased power can then be provided by using larger components. Hence it is less expensive to provide fewer large power supplies than to power the precipitator from a greater number of small sets. Because of the lower average voltage, however, the precipitation rate parameter would be lower, and the necessity for providing larger collecting surface area would partially offset the lower cost of the larger set.

Often, multiple cells are energized from a common high-voltage electrical set. However, no more than one field in any cell should be energized from the same high-voltage electrical set, because a short would affect more than one field in the same cell, causing a substantial reduction in collection efficiency. In general, one high-voltage electrical set is used for up to 2,320 m^2 (25,000 ft^2) of collecting surface. About 611 mA/1000 m^2 (55 mA/1000 ft^2) of collecting surface is supplied.

2.2.5 Ash Hoppers

Whether suspended from the casing or supported directly on the substructure that is interposed between the casing and the support steel, hoppers are required for collection and temporary storage of the collected dust. The simplest and most common hopper is pyramidal, converging to a round or square discharge. Frequently, the hoppers are baffled at the division between two dust-plate sections, to prevent gas bypassing the treater.

Hoppers must be kept clean and dry. Although many designs do not require vibrators, which are costly and require maintenance, it may be prudent to install mounting provision for vibrators initially, to avoid later costly removal of insulation and lagging if operation shows that vibrators are needed.

Moisture-laden dust that hits cold steel hoppers has a tendency to stick. Therefore, insulation of hoppers is vital. Insulation is sometimes not sufficient, however, and additional heating of the hoppers may be required for effective performance.

When a baffle extends too far down into a hopper, it may act as a "choke," causing bridging between the baffle and one or both sides of the hopper. Stopping the baffle a liberal distance 0.6 m (2 ft) clear of the sloping hopper wall should prevent gas bypassing. A gas sweep under a baffle of this type, considering the pressure drop of the turn, is probably a symptom of poor gas distribution to the precipitator (that is, a downward jet at the entrance).

Access to hoppers should be by external, key-interlocked doors. Bolt-on doors through baffles should be avoided because of the dangerous possibility of dust accumulation on the far side of the door. Liberal "poke-hole" ports should be provided to allow for clearing a blockage at the discharge.

Level alarms are extremely valuable, provided they are kept in working order. Too often, because they are located near the top of the hoppers (even so high as to place them above the bottom of the structural steel supporting the precipitator), they are inaccessible for periodic inspection and maintenance. Also, the temperature in this confined area may be so high as to cause the alarm mechanisms to fail; this point should be considered critically and in detail before installation of the alarm instrument.

Hopper capacity should be checked carefully to provide reasonable time for minor maintenance of the dust-removal system. Generally, hoppers are designed to accumulate a 24-hour load of particulate.

Alignment of the conveyors is important, depending to a great extent on the alignment of hopper connections. Because of the difficulty of erecting multiple hoppers to close alignment tolerances, field-adjustable flange connections are recommended. Also, the designer should not overlook provision for expansion between hopper connections and conveyor troughs.

3.0 MALFUNCTIONS

Many ESP equipment components are subject to failure or malfunction, leading to an increase in emissions. These malfunctions may be caused by faulty design, installation, or operation of the ESP; they may entail minor or severe problems with the ESP system. This section identifies several types of ESP malfunctions, giving probable causes and corrective actions. A survey of ESP operating experience of 63 electric utilities is analyzed.

3.1 TYPES OF ESP MALFUNCTIONS

ESP malfunctions can be classified as[1] electrical, gas flow, rapping, or mechanical problems. Table 3-1 lists common problems associated with ESP's, their effect on emissions, corrective actions, and preventive measures.

3.1.1 Discharge Wire Breakage

Probably the most common problem associated with suspended wire electrode type ESP's is wire breakage, which typically causes an electrical short circuit between the high-tension discharge wire system and the grounded collection plate. This electrical short trips the circuit breaker, disabling a section of the ESP, which will remain dis-

Reproduced from best available copy.

Table 3-1. SUMMARY OF PROBLEMS ASSOCIATED WITH ESP'S

Malfunction	Cause	Effect on ESP Efficiency[a]	Corrective action	Preventive measures
1. Poor electrode alignment	1) Poor design; 2) Ash buildup on frame hoppers; 3) Poor gas flow	Can drastically affect performance, and lower efficiency	Realign electrodes Correct gas flow	Check hoppers frequently for proper operation
2. Broken electrodes	1) Wire not rapped clean, causes an arc which embrittles and burns through the wire 2) Clinkered wire. Causes: a) poor flow area, distribution through unit is uneven; b) excess free carbon due to excess air above combustion requirements or fan capacity insufficient for demand required; c) wires not properly centered; d) ash buildup resulting in bent frame, same as c); e) clinker bridges the plates & wire shorts out; f) ash buildup, pushes bottle weight up causing sag in the wire; g) "J" hooks have improper clearances to the hanging wire; h) bottle weight hangs up during cooling causing a buckled wire; i) ash buildup on bottle weight to the frame forms a clinker and burns off the wire	Reduction in efficiency due to reduced power input, bus section unavailability	Replace electrode	Boiler problems: check space between recording steam & air flow pens, pressure gauges; fouled screen tubes. Inspect hoppers Check electrodes frequently for wear Inspect rappers frequently
3. Distorted or skewed electrode plates	1) Ash buildup in hoppers 2) Gas flow irregularities 3) High temperatures	Reduced efficiency	Repair or replace plates Correct gas flow	Check hoppers frequently for proper operation; check electrode plates during outages
4. Vibrating or swinging electrodes	1) Uneven gas flow 2) Broken electrodes	Decrease in efficiency due to reduced power input	Repair electrode	Check electrodes frequently for wear

[a] The effects of precipitation problems can only be discussed on a qualitative basis. There are no known emission tests of precipitators to determine performance degradation as a function of operational problems.

Table 3-1 (Continued). SUMMARY OF PROBLEMS ASSOCIATED WITH ESP'S

Malfunction	Cause	Effect on ESP Efficiency[a]	Corrective action	Preventive measures
5. Inadequate level of power input (voltage too low)	1) High dust resistivity 2) Excessive ash on electrodes 3) Unusually fine particle size 4) Inadequate power supply 5) Inadequate sectionalization 6) Improper rectifier and control operation 7) Misalignment of electrodes	Reduction in efficiency	- Clean electrodes; gas conditioning or alterations in temp. to reduce resistivity; Increase sectionalization	Check range of voltages frequently to make sure they are correct In situ resistivity measurements
6. Back corona	1) Ash accumulated on electrodes - causes excessive sparking requiring reduction in voltage charge	Reduction in efficiency	Same as above	Same as above
7. Broken or cracked insulator or flower pot bushing leakage	1) Ash buildup during operation causes leakage to ground 2) Moisture gathered during shutdown or low load operation	Reduction in efficiency	Clean or replace insulators & bushings	Check frequently Clean and dry as needed; check for adequate pressurization of top housing
8. Air inleakage through hoppers	1) From dust conveyor	Lower efficiency - dust reentrained through ESP	Seal leaks	Identify early by increase in ash concentration at bottom of exit to ESP
9. Air inleakage through ESP shell	1) Flange expansion	Same as above, also causes intense sparking		
10. Gas bypass around ESP: - dead passage above plates - around high tension frame	1) Poor design - improper isolation of active portion of ESP	Only few percent drop in efficiency unless severe	Baffling to direct gas into active ESP section	Identify early by measurement of gas flow in suspected areas
11. Corrosion	1) Temperature goes below dew point	Negligible until precipitation interior plugs or plates are eaten away; air leaks may develop causing significant drops in performance.	Maintain flue gas temperature above dew point.	Energise precipitator after boiler system has been on line for ample period to raise flue gas temperature above acid dew point.

[a] The effects of precipitation problems can only be discussed on a qualitative basis. There are no known emission tests of precipitators to determine performance degradation as a function of operational problems.

Reproduced from best available copy.

Table 3-1 (Continued). SUMMARY OF PROBLEMS ASSOCIATED WIH ESP'S

Malfunction	Cause	Effect on ESP Efficiency[a]	Corrective action	Preventive measures
12. Hopper pluggage	1) Wires, plates, insulators fouled because of low temperature 2) Inadequate hopper insulation 3) Improper maintenance 4) Boiler leaks causing excess moisture 5) Ash conveying system malfunction) gasket leakage) blower malfunction) solenoid valves 6) Misadjustment of hopper vibrators 7) Material dropped into hopper - from bottle weights 8) Solenoid, timer malfunction 9) Suction blower filter not changed	Reduction in efficiency	Provide proper flow of ash	Frequent checks for adequate operation of hoppers. Provide heater thermal insulation to avoid moisture condensation
13. Inadequate rapping, vibrators fail	1) Ash buildup 2) Poor design 3) Rappers misadjusted	Resulting buildup on electrodes may reduce efficiency	Adjust rappers with optical dust measuring instrument in ESP exit stream	Frequent checks for adequate operation of rappers
14. Too intense rapping	1) Poor design 2) Rappers misadjusted 3) Improper rapping force	Reentrains ash, reduces efficiency	Same as No. 13	Same as No. 13 Reduce vibrating or impact force
15. Control failures	1) Power failure in primary system 2) Transformer or rectifier failure a. insulation breakdown in transformer b. arcing in transformer between high voltage switch contacts c. leaks or shorts in high voltage structure d. insulating field contamination	Reduced efficiency	Find source of failure and repair or replace	Pay close attention to daily readings of control room instrumentation to spot deviations from normal readings
16. Sparking	1) Inspection door ajar 2) Boiler leaks 3) Plugging of hoppers 4) Dirty insulators	Reduced efficiency	Close inspection doors; repair leaks in boiler; unplug hoppers; clean insulators	Regular preventive maintenance will alleviate these problems

[a] The effects of precipitation problems can only be discussed on a qualitative basis. There are no known emission tests of precipitators to determine performance degradation as a function of operational problems.

abled until the broken discharge wire is removed from the unit.

Following are the principal causes of discharge wire breakage:

1) Inadequate rapping of the discharge wire causing an arc, which can embrittle the wire and eventually break it completely.

2) Clinkered or improperly centered wires causing a continual spark from the wire to the bracing.

3) Clinker or a wire that bridges the collection plates and shorts out the wire.

4) Ash buildup under the wire, causing it to sag and short out.

5) Improper clearance of "J" hooks to the wire, causing it to short out.

6) Hangup of a bottle weight during cooling, causing a wire to buckle.

7) Fly ash buildup on a bottle weight, which forms a clinker or burns off the wire.

8) Corrosion around cooler areas of the wire caused by condensation.

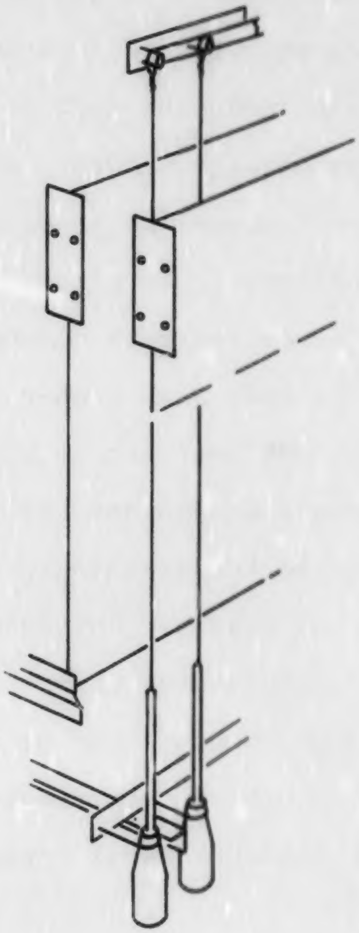
9) Excessive localized sparking causing erosion of the wire.

Electrical erosion, the predominant cause of failures, occurs when repeated electrical sparkovers or arcs occur in a localized region. A sparkover causes localized heating and vaporization of a minute quantity of metal with each spark. If the sparkover occurs at random locations, no serious degradation of the discharge electrode occurs. If the sparkover occurs repeatedly at the same location, however, significant quantities of material can be removed, with subsequent reduction of cross-sectional area and ultimate failure at that point.[3]

Localized sparking can be caused by misalignment of the discharge electrodes during construction or by electric field variations caused by "edge" effects where the discharge and collection electrodes are adjacent to each other at the top and the bottom of the plates. Corrective measures for eliminating failure at these points are adding shrouds, such as those shown in Figure 3-1, and providing a rounded surface at the edge of the collection electrode to reduce the tendency for sparking.[3]

Electrical erosion can also be caused by "swinging" electrodes, which can occur when the mechanical resonance frequency of the discharge wire and weight system is harmonically related to the electrical frequency of the power supply. The power supply adds energy to the swinging wire and it continues to approach the collection plate with sparking occurring at each close approach. This action leads to erosion of the electrode and mechanical failure.[3]

Poor workmanship during construction can also cause electrical failures of the discharge electrode. If pieces of the welding electrode remain attached to the collection



(Source: Ref. 3)

Figure 3-1. Shrouds for wire-weighted discharge electrodes.

plate, localized electric field deformation can lead to sparking and ultimate failure of the discharge electrode.

Mechanical fatigue occurs at points where wires are twisted together and a continued mechanical motion occurs at one location. This situation is found at the top of a discharge electrode where the wire is twisted around the support collar. Methods of reducing mechanical fatigue include selection of discharge electrode material that is less susceptible to cold work annealing after attachment or modification of the design of the corona wire attachment.

Chemical attack is caused by a corrosive material in the flue gas, as is the case with high-sulfur coal and low flue gas exit temperatures near the acid dew point. Another cause of corrosion is use of ambient air to purge insulator compartments, causing the temperature to drop below the acid dew point in a localized region. Corrosion can be minimized with higher flue gas temperatures or by use of hot, dry air to purge insulator compartments. Use of good insulation on the ESP shell to maintain high temperature also provides adequate protection within the usual range of temperatures and sulfur contents.[3]

The other causes of discharge wire failure, such as inadequate rapping, could be minimized by routine checking of vibrators and rappers. Inspection may help to prevent wire failures and tripouts by detecting potential problems before they become serious. Because of the large number of wires contained in an ESP, however, some discharge wire failures can be expected even with good design and preventive maintenance.

3.1.2 Collection Hoppers and Ash Removal

Hoppers and ash removal systems often constitute problems in precipitator operation. If the hoppers become full, the collected dust may short-circuit the precipitator. The power through the dust may fuse the dust, forming a large clinker-type structure called a "hornet's nest." This structure further interferes with ash removal and must be removed. Most problems associated with hoppers are related to providing for proper flow of the dust. Improper adjustment of the hopper vibrators or failure of the conveyor system are the usual causes of failure to empty the hoppers. It may be necessary to provide heat and/or thermal insulation for the hoppers to prevent moisture condensation and resultant cementing of the collected dust.

Malfunctions of the evacuation and removal system include ash water pump failure, water jet nozzle failure, disengagement of vacuum connections, and failure of sequencing controls.

The best preventive measure for an ash removal system, aside from proper design, is a good program for operation and maintenance. Since dust buildup can affect so many of the ESP components, proper ash removal will eliminate or minimize many of the most common ESP malfunctions.

Gas flow problems affect hoppers as a result of the inleakage of air into hoppers from the dust conveyor systems. This results in reentrainment of collected dust, which is carried back into the ESP. Air inleakage can also occur through the ESP shell or inlet flanges if operation is at less than atmospheric pressure. Often enough air is bled in to cause intense sparking.

'Gas sneakage' is a term used to describe gas flow that bypasses the effective ESP section.[1] It can occur through dead passages of the ESP above the collector plates, around the high-tension frame, or through the hoppers. Gas sneakage will reduce ESP efficiency by only a few percent unless it is unusually severe. Gas sneakage can be identified by measuring gas flows in suspected areas in a nonoperating or cold test. Corrective measures usually involve baffling to direct gas into the active ESP section.

Reentrainment of dust from hoppers caused by air inleakage or gas sneakage is often indicated by an increase in dust concentration at the bottom of the exit to the ESP.

Corrective measures for air leakage would include proper design and fit of components and sealing of areas where the inleakage occurs.

3.1.3 Rappers or Vibrators

Rapping is required for both discharge and collection electrodes. These systems normally consist of electric or pneumatic vibrators or electromagnetic or mechanical-impact rappers.

In dry removal systems, rapping of the collection electrode to remove dust is normally done periodically. Successful rapping depends upon accumulation of material on the plate thick enough that it falls in large agglomerates into the hopper. Although there is always some reentrainment of dust, effective rapping must minimize the amount of material reentrained in the gas stream. Poor performance can result from rapping forces either too mild or too severe. Rapping that is too intense and frequent can result in a clean plate, with the collected dust being reentrained rather than falling into the hopper. Excessive gas velocity or poor gas distribution can lead to turbulence, scouring of the receiving electrode, and reentrainment of particles.

Inadequate rapping of the discharge electrodes can result in heavy dust buildup with localization of the corona, low corona current, and excessive sparking, as discussed previously. Poor gas flow and the condition of the dust also can cause formation of deposits on discharge electrodes. Often, deposits can reach to 5 cm (2 in) thickness; they are generally composed of the finer dust particles and often cling tenaciously to the discharge wire. Deposits on the discharge wire do not necessarily lead to poor performance, although depending on resistivity, power supply range, and uniformity of the deposit, efficiency may be reduced.

Variations in design of the support structure and of the electrodes can also result in inadequate rapping. Recent investigations of rapping acceleration in fly ash ESP's have shown measured accelerations of 5 g when as much as 30 g may be required.[9] The first step in dealing with problems related to rappers and vibrators would be to determine the adequacy of the rapping acceleration with an accelerometer mounted on the plates. A common method of adjusting rappers is with the use of an optical dust-measuring instrument in the ESP exit gas stream.

Discharge electrodes should be kept as clean as possible. Rapping intensity in this case is limited only by the possibility of mechanical damage to the electrodes and support structure.

Generally, the vibratory types of cleaning mechanisms require more maintenance than the impulse types.

3.1.4 Insulator/Bushing Failure

Suspension insulators are used to support and isolate the high-voltage parts of an ESP. Inadequate pressurization of the top housing the insulators can cause ash deposits and/or moisture condensation on the bushing, which may result in electrical breakdown at the typical operating potential of 45 kv-DC.

Corrective or preventive measures include inspection of ventilation fans for the top housing and availability of a spare fan for emergencies. Frequent cleaning and checking for damage of the fans by vibration is also necessary to ensure trouble-free operation.

3.1.5 Inadequate Electrical Energization

Since an ESP operates on the basis of electric field and electric charge, electrical energization must be adequate to provide for particle charging, maintenance of the electric field, and holding the collected dust to the collection plates.

Among several possible causes for inability to achieve the required level of power input to the ESP, the following are most common:[1]

1) high dust resistivity

2) excessive dust accumulation on the electrodes
3) unusually fine particle size
4) inadequate sectionalization
5) improper rectifier and control operation
6) misalignment of electrodes
7) inadequate power supply range

If a precipitator is operating at a spark-rate-limited condition but with low current and voltage, the problem commonly can be traced to high-resistivity dust, electrode misalignment, or uneven corona due to buildup on the discharge electrode.

The effects of high resistivity are discussed in more detail in Section 3.2 in terms of conditions specific to utility industry, where resistivity presents the greatest problem.

Because of the importance of resistivity in the precipitation process, _in situ_ resistivity measurements should be made as one of the first steps in troubleshooting. If the resistivity is found to be high (more than 10^{10} ohm-cm), most of the difficulty may be due to this cause. If resistivity is not high, other potential causes of abnormally low currents should be investigated.

Typical values for normal power supply operation range from 33 to 103 mA/1000 m (10 to 31 mA/1000 ft) of collecting surface. The spark rate should be adjusted to give about 10 to 100 sparks/min per section. The spark rate should be set to give maximum average high-tension voltage, usually resulting in spark rates in the range shown above.

If a precipitator is operating in a spark-limited mode with abnormally low voltage on dust with resistivities less than 10^{10} ohm-cm, the problems are likely to be associated with misalignment of electrodes, uneven deposits on the discharge wire, or broken corona wires.

Occasionally, precipitators may be found to operate at the maximum voltage or current settings on the power supply with no sparking. This condition is likely to be associated with the collection of low-resistivity dusts, where the electric field in the deposit is insufficient to initiate sparking. These installations are referred to as "power hogs." The fact that the precipitator is not sparking does not necessarily mean that the unit is underpowered. These installations may have sufficient power to provide adequate charging and collection electric fields without sparking. If ESP efficiencies are low and tests show that sufficient power is provided, then other disruptive conditions should be sought.

Failures in ESP controls can prevent the system from achieving the level of power required for normal operation. Following are the most common malfunctions in controls:

1) Power failure in the primary system.

2) Transformer or rectifier failure in secondary system.

   a. insulation breakdown in transformer
   b. arcing in transformer between high voltage switch contacts
   c. leaks or shorts in high voltage structure
   d. contamination of the insulating field

The most effective measure for correction of control failures is a good maintenance program in which the controls are checked periodically for proper operation. A daily log of instruments that register current, voltage, and spark rate can also indicate potential problems.

3.2 CONDITIONS SPECIFIC TO POWER PLANTS THAT CAUSE PROBLEMS IN PRECIPITATORS

A number of operating conditions specific to power plants can cause ESP problems, often requiring special equipment designs. The major operating problems are caused by startup, variable fuel quality, boiler malfunctions, fly ash resistivity, temperature fluctuations, and large gas volumes. Each is briefly discussed below.

3.2.1 Startup

Normally, during startup of a coal-fired steam generator equipped with an ESP, operation of the ESP must be delayed until a certain exit gas temperature (about 110°C (230°F)) is attained. This delay is necessary to protect the ESP from corrosion and plugging, and to prevent secondary combustion (fires) due to unburned carbon in the flue gas and ESP sparking. The latter is particularly important when secondary liquid fuels are used during startup.

3.2.2 Fuel Quality Variability

Variable fuel quality is a major cause of changes in operation that lead to fluctuating emissions. The quality of fuel from a given source is continually changing. As sulfur and ash content vary, so does the efficiency of the ESP. Excess moisture in the coal can lead to wet fly ash, which could interfere with the dampers and solidify in the hoppers. Ash grindability, fineness and other coal characteristics can cause combustion to deviate from the optimum, requiring changes in such operating variables as register settings and excess air.

Although the variability of sulfur and ash contents in coal cannot be readily controlled, proper drying of the coal before combustion can minimize the possibility of wet fly ash and the resultant problems.

3.2.3 Boiler Malfunctions that Indirectly Affect ESP Performance

Firebox flameout, coked or burned burner impellers, improper combustion due to faulty fans or dampers, irregular fuel flow to coal mills, pulverizer problems, excess slag buildup in the firebox, and soot blower usage all can upset precipitator performance and cause emissions to increase.

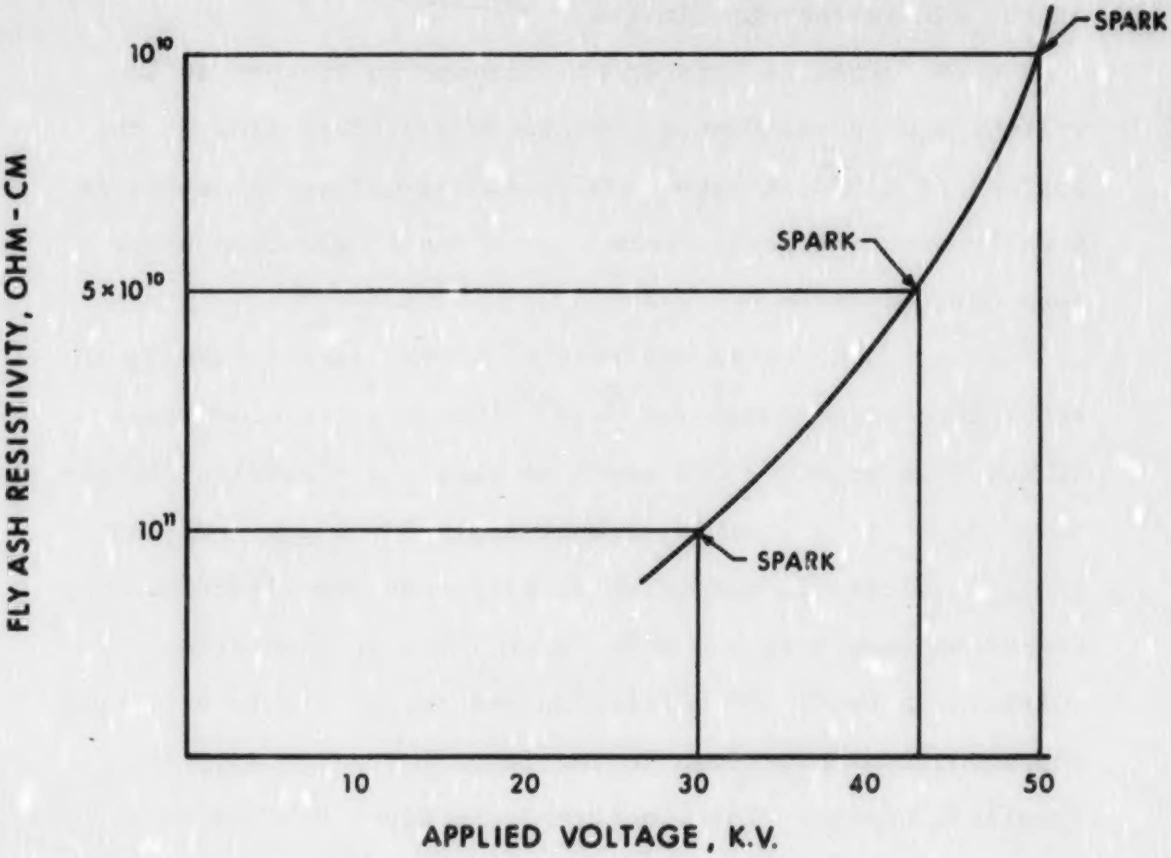
Usually, these upsets are of short duration. Proper maintenance can minimize these types of boiler malfunctions and increase ESP reliability.

3.2.4 High Resistivity of Fly Ash Resulting from Low Sulfur Content in Coal

High resistivity, which is characteristic of low-sulfur coal, causes uncertainties in proper sizing of a cold ESP. In addition, many operating problems can be traced directly or in part to high resistivity.[1]

High dust resistivity affects ESP efficiency principally by limiting the voltage and current at which the ESP operates. If the ESP electrodes are clean, the high-tension voltage can be increased until a sparking condition is reached. The maximum voltage is determined principally by gas composition and ESP dimensions.

If dust is deposited on the collection electrode, the voltage at which sparking occurs is decreased because of the increased electric field at the dust surface. If the resistivity of the dust layer is increased, the voltage at which sparking occurs will be further reduced, as shown in Figure 3-2. Finally, at very high values of dust resistivity (10^{12} ohm/cm), the voltage will be reduced enough that sparks will not propagate across the interelectrode space. Under these conditions, the gas in the interstitial regions of the dust layer will break down at very low values of



(Source: Ref. 10)

Figure 3-2. Typical sparking levels when precipitating dusts with different resistivities.

applied voltage and current density, resulting in a back corona. The positive ions resulting from this corona flow toward the discharge electrode and neutralize the negative charge previously applied to the dust particles; performance of the ESP is thereby limited.

Back corona results in an increase in current at low voltage and is manifested visibly as a diffuse glow at the surface of the dust layer. Although visual verification is usually very difficult, back corona can be observed under very dark conditions.

If the electrical resistivity of the particulate is in the intermediate range (10^{10}-10^{12} ohm-cm), the electrical behavior is somewhat different in that the electrical breakdown occurs at a somewhat higher applied voltage. If the applied voltage is sufficiently high when the electrical breakdown occurs in the dust layer, then an electrical sparkover between the collection and corona electrode occurs. The electrical breakdown in the layer tends to begin in a localized region. This localized breakdown behaves as a small radius of curvature electrode (a point). This leads to electrical sparkover at reduced voltages in the operating device, again forcing the electrostatic precipitator to operate at reduced voltage and current density.

The reduction in electrical conditions is much more severe with back corona than with sparkover at reduced voltage.[3]

In addition to electrically limiting the performance of an ESP, high-resistivity dust can cling much more tenaciously to collection electrodes than an intermediate-resistivity dust. Therefore, a much greater rapping acceleration must be applied to the electrode to remove the dust layer. This increased acceleration may be so great as to cause severe reentrainment of the dust, or damage to the precipitator if it is not designed to accommodate such high acceleration.

Corrective procedures for ESP's that are limited by high-resistivity ash include collection at low temperatures [105-110°C (220-230°F)], use of very large ESP's, increased sectionalization, and use of conditioning agents. "Conditioning agents" have been used for many years to improve the collection of particulate substances in electrostatic precipitators.[1,2] Normally, the use of a conditioning agent is expected to overcome the problems associated with high electrical resistivity. In some instances, however, conditioning agents may alleviate other problems stemming from adverse particulate properties, one being unacceptably low resistivity.[11]

The best known conditioning agent is sulfur trioxide or the chemically equivalent compound, sulfuric acid. In most applications, sulfur trioxide is effective in lowering electrical resistivity by surface deposition along with water vapor on gas-borne particles. In conditioning fly ash in power plants, it supplements the small quantity of sulfur trioxide that is produced naturally when low-sulfur coals are burned.[12,13] On the other hand, in some power plants where sulfur content of the coal is not especially low and the fly ash resistivity is not low enough to be detrimental to electrostatic precipitation, the use of sulfur trioxide as a conditioning agent may be of value in increasing the cohesiveness of fly ash particles and thus minimizing reentrainment losses from the collection electrodes. Evidence of sulfur trioxide conditioning through this mechanism has been reported in a publication from the Central Electricity Research Laboratories in Great Britain;[14] further evidence of this effect has been obtained in recent studies by Southern Research Institute.[15]

Other conditioning agents, not as well known as sulfur trioxide, include ammonia, ammonium sulfate, ammonium bisulfate, and sulfamic acid. Of these compounds, ammonia has been most widely used in the utility industry. Experience with ammonium sulfate, ammonium bisulfate, and sulfamic acid has thus far been relatively limited.[16] These compounds occur at normal temperatures and pressures as solids. They are injected into flue gas in the form of either a fine powder or an aqueous solution.

As an alternative to the above-listed corrective procedures, use of a hot ESP will largely eliminate the problems.

3.2.5 Temperature Fluctuations

During frequent startup and shutdown operations, or with a boiler that is used mostly for peak loads, the flue gas exhibits a large temperature gradient. If the temperature drops below the dew point of sulfuric acid, corrosion can occur. In such operations, control of temperature changes is difficult but corrosion can be minimized by covering the interior surfaces of side frames, end frames, and roof of the ESP with gunite.

Another effect of temperature fluctuations is reentrainment of fly ash, resulting in excessive fouling of wires, plates, and insulators. This fouling leads to ash hopper plugging, high current, leakage, and excessive power requirement for the discharge electrodes. The most effective measure for dealing with unfavorable temperature fluctuations is to evaluate the range of expected gas temperatures when designing the ESP and to provide a means of reaching the optimum gas temperature for proper ESP operation. After a unit is installed, temperature changes can be dealt with by increasing the size of the ESP with add-on equipment.

3.2.6 Large Gas Volumes

Utilities treat larger volumes of gas than most other industries. Since large gas volumes require large precipitators, space considerations may become critical. In addition, as more bus sections are required, the precipitator becomes more complex and the chances for problems increase.

3.3 REDUCED ESP COLLECTION EFFICIENCY AS RELATED TO NUMBER OF BUS SECTIONS NOT IN OPERATION

Although ESP collection efficiency is reduced by malfunctions such as discharge wire breakage and deterioration of power supply equipment, rectifiers, insulators, and similar equipment, a unit can often be kept in compliance with particulate emission regulations by reducing boiler load. Figure 3-3 (top graph) illustrates collection efficiency of a four-field ESP with 24 bus sections as a function of the gross boiler load, depending on the number of bus sections out and whether they are in series or parallel. The bottom graph shows the efficiency needed by the ESP to meet a state regulation of 0.16 g/MJ (0.38 lb/MM Btu) as a function of the ash content of coal [(assuming 25.6 MJ/kg coal (11,000 Btu/lb coal)].

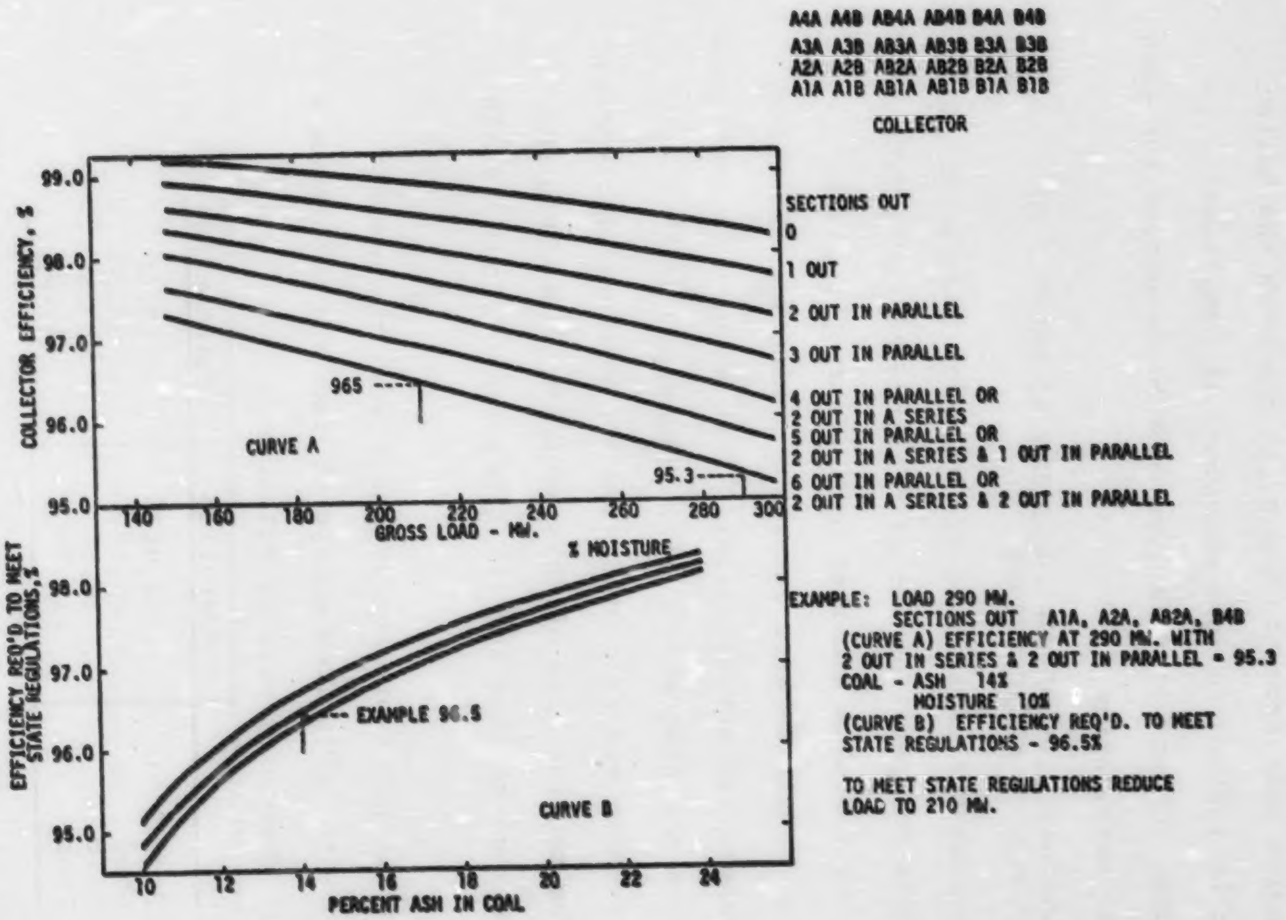


Figure 3-3. Typical operating curve to meet emission regulations with partial malfunctions of ESP.

These types of graphs are extremely helpful to a utility operator. Knowing the ash content of the coal he is firing and knowing which bus sections of his ESP are inoperative, he can easily tell from the top graph how much the boiler load must be reduced to keep emissions in compliance with regulations. Charts of this type must be developed for each boiler-ESP combination.

3.4 MAINTAINABILITY OF ESP EQUIPMENT AS RELATED TO FREQUENCY OF MALFUNCTIONS

To assess the experience of the major industries in recent years in operation and maintenance of ESP's, the TC-1 Committee of the APCA embarked upon a survey in 1974.[17] Four major industries were canvassed: electric utilities, cement, paper, and metallurgical. This section is restricted to data from the electric utility industry.

Sixty-three electric utilities reported on eighty-eight ESP's. The service life of this equipment was not given, but the average service for the study ranged from 7 to 10 years.

The first point of inquiry dealt with the overall experience with ESP's from an operational and maintenance viewpoint. Responses were as follows:

	Operation	Maintenance
Excellent	14.8%	13.6%
Good	45.5%	52.3%
Fair	29.5%	13.6%
Poor	10.2%	20.5%

The second question dealt with specific areas of potential difficulty. With respect to failure of discharge electrodes, results were as follows:

Frequency of Discharge Electrode Failures

Frequent - 29.5%
Infrequent - 38.6%
Very Seldom - 28.4%

Of the three major types of failures normally experienced (fatigue, corrosion, electrical arcing), 61.7 percent of all industries indicated that electrical erosion (arcing) was the major cause. Corrosion and fatigue ranked second and third respectively. This ranking is probably typical of the electric utility industry.

Failure in the rapping system, which usually includes electric or pneumatic vibrators or electromagnetic or mechanical impact-type rappers, was evaluated as follows:

Frequency of Rapper or Vibrator Failures

Frequent - 9.1%
Infrequent - 38.6%
Very Seldom - 47.7%

As would be expected, the data indicated that the vibratory type of mechanism requires more maintenance than the impulse type.

Frequency of problems created by collecting surfaces was listed as follows:

Frequent - 4.5%
Infrequent - 7.9%
Very Seldom - 68.2%

The major cause cited for collecting surface failure was fatigue at the points of plate suspension. Corrosion was ranked as the second major cause.

Removal of dust, once precipitated, is historically one of the major causes of precipitator malfunction, contributing also to other difficulties, such as discharge electrode failure. The survey showed the following frequency of dust removal problems:

Frequent - 36.4%
Infrequent - 42.0%
Very Seldom - 20.5%

By far, the majority of problems cited were with plugging of the dust hopper. Difficulties with screw conveyors and dust valves were ranked second and third.

Suspension insulators, manufactured of glazed porcelain, fused silica or alumina oxide, are used to support and isolate the high-voltage elements of a precipitator. These insulators are vulnerable to failure due to electrical arc-over resulting from accumulations of dust or moisture. Regarding problems with suspension insulators, the utilities indicated the following:

Frequent - 8.0%
Infrequent - 34.1%
Very Seldom - 48.9%

It is apparent that this is not a significant source of operational difficulty.

The final phase of the survey asked the user's opinion of which ESP components were the major cause of trouble in his experience, in terms of both reliability and expense. The responses, again based on 63 utilities reporting on 88 ESP's, were as follows:

Major Maintenance Problems

Discharge Electrodes - 35.2%
Dust Removal Systems - 5.7%
Rappers or Vibrators - 13.6%
Collecting Plates - 31.8%
Insulators - 1.1%

Several conclusions may be drawn from the results of this survey:[17]

1. Although precipitator manufacturers obviously can improve their products, most of the utilities reporting are satisfied with the precipitator as a functioning piece of equipment. Only 10.2 percent gave a "Poor" rating.

2. Discharge electrodes are the principal source of malfunction, requiring application of design expertise. Recognizing this, ESP manufacturers are concentrating on design improvements.

3. Design, operation, and maintenance of the dust removal system are extremely important. The utilities reported a high incidence of discharge electrode failure along with a high degree of hopper pluggage. Dust buildup into the high-voltage system, in addition to inhibiting performance, can accelerate failure of discharge electrodes.

The TC-1 Committee of the APCA suggested close cooperation between user and supplier, coupled with exchange of information between the various user industries. Such a program could lead to mutual development of an electrostatic precipitator that fills the needs of the users.

The survey was only the initial phase of a comprehensive study of experience with high-efficiency collectors of various types. The survey data are considered preliminary, in that considerably more detail can be derived statistically. The TC-1 Committee is continuing work with this data base and intends to report additional findings, conclusions, and recommendations.

4.0 MAINTENANCE

This section presents a program for ESP surveillance and maintenance that could enable a utility to reduce malfunctions and downtime. It describes typical procedures followed by utilities during startups and malfunctions, and discusses costs of ESP maintenance.

4.1 MAINTENANCE PROGRAM FOR PRECIPITATORS

Table 4-1 lists items to consider in establishing maintenance procedures for ESP's. Table 4-2, given at the end of this subsection, is a troubleshooting chart for use in determining the cause of common ESP malfunctions, with suggestions for remedying these problems.

4.1.1 Operational Procedure

Prestartup Inspection[9] - Before implementing startup procedures, all precipitator components must be thoroughly inspected to ensure that equipment is ready for operation.

General

1. Visually inspect the mechanical dust collector units, induced draft fans, and dust handling equipment.
2. Close and secure all access hatches.
3. Determine that all internal areas are completely free of tools, scrap and foreign material before the fan(s) is started.

Table 4-1. MAINTENANCE ITEMS FOR ELECTROSTATIC PRECIPITATORS

A. Daily Log

   1. Boiler operating parameters
   2. Flue gas analysis
   3. Coal characteristics
   4. Particulate collector control readings
   5. Transmissometer calibration

B. Daily

   1. T-R electrical control set readings
   2. Rapper and vibrator control settings
   3. Ash removal system
   4. Check T-R control room ventilation system

C. Weekly

   1. Check rappers and vibrators visually for proper operation
   2. Check control sets internally for dirt
   3. Make sure air filters to control sets and precipitator top housing are not plugged

D. Monthly Log

   1. Check precipitator top housing for pressurization
   2. Check standby fan operation manually

E. Quarterly

   1. Clean and dress HW-FW electrical distribution contact surfaces
   2. Lubricate pivots

F. Semi-Annually

   1. Clean and lubricate access door hinges and test connections

Table 4-1 (cont'd). MAINTENANCE ITEMS FOR ELECTROSTATIC PRECIPITATORS

2. Perform exterior inspection for loose insulation, corrosion, loose joints, etc.
3. Check for gas leakage points in or out

G. Annually

1. Perform thorough internal inspection
    a. check for possible leaks of oil, gas or air at gasketed connections
    b. check for corrosion of any component
    c. check for broken or misaligned wires, plates, insulators, rappers, etc.
    d. check high voltage switch gear and interlocks
    e. clean all insulators and check for hairline cracks or tracking
    f. check expansion joints on hot precipitators
2. Check for signs of hopper leakage, reentrainment of particulate, and poor gas distribution
3. Check for dust buildup in inlet and outlet flues
4. Check for dust buildup in hoppers

4. Verify that primary power is available to thermostatically controlled heaters if provided. Circuit breakers for this equipment may have to be energized several hours prior to system operation.

5. Check all interlocks and voltage control modules.

6. Check main OFF/TEST Selector Switch and place in OFF position.

7. Check grounding connections.

Rapper System

1. Ground the power unit in the control cubicle.

2. Check distributor switch rapper connections.

3. Check ground return leads for proper connections to sectionalized control adjustments.

4. Check for proper mechanical adjustment.

5. Adjust each manual sectional control for proper rapping intensity.

6. Check spark rate feedback circuit and signals for proper connections.

Rectifiers and Transformers

1. Check all connections, switches, and insulators.

2. Check oil (liquid) levels.

3. See that high-tension duct vent ports are installed and free.

4. Be sure grounds are completed on transformer-rectifiers, bus duct, and conduits.

Routine Startup

If hot gases are to be passed through the precipitator, the system should be warmed to operating temperature before gas flows are started. (See Section 4.2). The following procedures are then performed.

Close all inspection ports and adjust dampers for proper air flow.

Energize high-voltage current.

Start collector and discharge electrode rappers, if provided on the system.

Turn on ash discharge system.

Bring fan to full rpm with exit damper closed.

Adjust damper for desired gas flow.

Record system pressure drop and fan pressure drop.

If the system is not equipped with external heating facilities, the procedure should be reversed so that the inlet gases enter before the precipitator is energized. When the precipitator reaches operating temperature, turn on the high voltage power.

If the precipitator contains air and a potentially explosive gas mixture is introduced into the unit, the system must first be purged with an inert gas.

Any conveying systems that follow the hopper conveyor must be turned on before the hopper conveyor.

Routine Operation

Check pressure drops to prevent unusually high or low values.

Maintain precipitator current at normal level. Correct any deviations greater than about 5 percent of normal current.

Maintain sparking rate at optimum density.

Maintain rapper frequency and intensity to give maximum collection efficiency.

Check to see that thermostatically controlled heaters are properly operating.

If combustible gases are present in the precipitator, check the gas composition to be sure it is not in the explosive range.

See that all water cooling requirements are properly met, including any water-cooled bearings or pump stuffing boxes. Check all drive belt tensions daily. Periodically test fan inlet dampers to verify that the dampers are free to move to fully closed and fully opened positions. Inspect all electrode and collector rapper mechanisms daily for defective systems. Examine insulators daily for potential deterioration. Lubricate hopper conveyors and valves daily. Lubricate dampers and louvers to see that they function freely.

Instrumentation to register current, voltage, and spark rates to the precipitator can be red-lined to indicate norms. Abnormal readings indicate trouble; if these signs are ignored, serious equipment failures can result in excessive emissions and plant shutdown. Shutdowns can usually be prevented if operators heed warning signals.

Routine Shutdown

Shutdown is performed in reverse fashion from startup. Deenergize the precipitator, purge if necessary, then shut off gas flow. When all collectors and electrodes have been rapped clean, discontinue use of rappers. When hoppers are empty, turn off conveyors and discontinue any liquid washing.

4.1.2 Maintenance[9,18]

Maintenance of precipitators falls into categories of preventive maintenance and maintenance to correct failures. A preventive maintenance schedule should be established for each installation, detailing the precipitator parts to be checked and maintained daily, weekly, monthly, quarterly, semiannually, annually, and on a situational basis.

Daily - It is obvious that gross departures from normal readings on the transformer-rectifier meter and transmissometer indicate trouble. It is not so widely recognized that small variations, often too slight to be noticed without checking of daily readings, can indicate impending trouble.

Problems that usually have a gradual, rather than sudden, influence on precipitator performance include (1) air inleakage at air heaters or in ducts leading to the precipitator, (2) dust buildup on precipitator internals, and (3) deterioration of electronic-control components.

Such problems can be indicated by small, but definite, drift of daily meter readings away from baseline values.

Grossly abnormal readings indicate a serious problem, and also may aid in diagnosing the probable cause. For example, sudden tripout of an apparently normal electrical set probably indicates a short or ground in the secondary circuitry. A low but steady voltage reading indicates a high-resistance ground - such as that from discharge wires to ground through ash accumulating above a plugged hopper or from clinker formation on a wire.

Fluctuating voltage, dipping to low values, suggests a broken and swinging discharge electrode. Fluctuation of spark-rate meter readings does not necessarily indicate a problem unless there is confirmation by fluctuating voltage and/or current readings.

Operators should never try to correct deviant meter readings by adjusting control set points. An automatic-control response range should accommodate normal variations in load conditions. If major changes occur, such as would result from switching to a coal substantially different from that for which the precipitator was designed, the precipitator manufacturer should be called in to retune the installation. If no such major changes have occurred, then variant meter readings indicate problems that must be detected and corrected.

Probably 50 percent of all electrical set tripouts are caused by ash buildup. Short of set tripout, buildup above the top of hoppers can cause excessive sparking that erodes discharge electrodes. Further, the forces created by growing ash piles can push internal components out of position, causing misalignment that may drastically affect performance. Field engineers note that utilities sometimes attempt to preserve alignment by welding braces to hold collecting-electrode plates in position. This practice is inadvisable, since restraining the plates interferes with the effectiveness of the rapping action that keeps them clean.

Although various indicators and alarms can be installed to warn of hopper-ash buildup and of ash-conveyor stoppage, the operator car doublecheck by testing skin temperature at the throat of the hopper with the back of the hand. If the temperature of one or more hoppers seems comparatively low, the hopper heaters may not be functioning properly. Generally, however, low temperature indicates that hot ash is not flowing through the hopper and that bridging, plugging, or failure of an automatic dump valve has held ash in the hopper long enough for it to cool. The ash collected subsequently will pile up at the top.

If the temperature of all hoppers appears low to the touch, the operator should check the ash-conveyor system to see if it has stopped or if dust agglomeration is so great that the conveyor can no longer handle all of the fly ash.

Hopper plugging is sometimes caused by low flue-gas temperature, which permits moisture condensation. This results from carrying the boiler exit-gas temperature too low or from excessive leakage of ambient air into the flue-gas duct. Hoppers are particularly prone to plugging during startup after an outage, when they are cold and normally damp.

Daily checking of the control-room ventilation system minimizes the possibility of overheated control components, which can cause drift of control set points and accelerated deterioration of sensitive solid-state devices.

Weekly - Solenoid-coil failures, fairly common when high voltage was used, are rare with modern low-voltage equipment. Still, a weekly check of all units is advisable. Rapper action should be observed visually, and vibrator operation confirmed by feel. In addition, since rapping accelerations of 30 g are often required for proper collection, an accelerometer mounted on the plates should be checked to verify that rapping acceleration is adequate. This is best done on a pretest check.

Control sets must be checked internally for deposits of dirt that may have penetrated the filter. Accumulation of dirt can cause false control signals and can damage such large components as contactors and printed circuits.

Finally, filters in the air supply lines to control cabinets and the precipitator top housing should be checked and cleaned if necessary to prevent plugging.

Monthly - Most new precipitators incorporate pressurized top housings that enclose the bushings through which high-voltage connections are made to the discharge electrodes within the precipitator box. Pressurization assures that, if there is gas leakage where the bushings penetrate the precipitator hot roof, gas flow will be into the precipitator rather than out from it. Leakage from the precipitator into the housing could cause ash deposits and/or moisture condensation on the bushings, with risk of electrical breakdown at the typical operating potential of 45 kV d.c.

Inspect bushings visually and by touch for component vibration. Check differential pressure to be sure that the fan that pressurizes the housing is in good operating condition. Also, operate manually the automatic standby fan to make sure it is service-ready.

Quarterly - Quarterly maintenance includes inspection of electrical-distribution contact surfaces, which should be cleaned and dressed and the pivots lubricated, if this is not done even more frequently. These could cause false signals. Further, since transmissometer calibration is subject to drift, calibration should be verified to avoid the possibility of false indications of precipitator performance.

Semiannually - Routine inspection, cleaning, and lubrication of hinges and test connections should be done semiannually. If this task is neglected, extensive effort eventually will be required to free up test connections and access doors, involving expensive downtime. Performance tests may be required at any time, and should not be delayed while connections are made usable. An effective preventive measure is to recess fittings below the insulation.

Exterior inspection for corrosion, loose insulation, exterior damage, and loose joints can identify problems while repair is still possible. Special attention should be given to points at which gas can leak out as fugitive emissions.

Annually - Scheduled outages must be of sufficient duration to allow thorough internal inspection of the precipitator. Checks should be made for (1) possible leakage of oil, gas, or air at gasketed connections, (2) corrosion where heat loss is great or gas temperatures are low, and (3) possible misalignment of internal components. Also, high-voltage switchgear should be inspected for possible binding, misalignment, or defeated interlocks - defects that create a safety hazard in addition to reducing performance.

All insulator support bushings, rapper insulators, and antisway insulators should be cleaned and inspected for hairline cracks and evidence of tracking. Faulty insulators can cause excessive sparking and voltage loss, and can fail abruptly, possibly even explode, if allowed to deteriorate.

If the precipitator is located between the air heater and the boiler, expansion joints must be checked and slide plates lubricated. Finally, if necessary, all collection plates and electrode wires should be cleaned manually.

Situational - Certain preventive-maintenance and safety checks are so important that they should be performed during any outage of sufficient length, without waiting for scheduled downtime. Air flow readings should be compared with baseline values to detect possible performance deterioration. Further, meter readings taken immediately upon restoring the precipitator to service can serve as a check on any changes that may have resulted from maintenance done during the outage.

Critical internal alignments should be checked whenever an outage allows and immediate corrective action taken if misalignment is discovered. Control-cabinet and top-housing interiors should be checked during any outage of 24 hours or more and cleaned if necessary. Any outage of more than 72 hours provides an opportunity to check grounding devices, alarms, interlocks, and other safety equipment, and to clean and inspect insulators and bushings.

Safety

It is obvious that high-voltage electricity can be extremely dangerous. Therefore, all practical safety measures must be observed even though the system incorporates interlocks and other safety devices.

The system should never be adjusted with the high-voltage power on.

Rectifiers and diodes have heat sinks that could seriously shock a person touching them.

The rapper circuitry, which is independent of the high-voltage circuitry, is nonetheless also dangerous and must be treated as such.

Spark-rate feedback signals are often taken from the primary of the high-voltage supply and can be 400 V a.c. or more. Fuses on these lines should be removed before maintenance or adjustment is attempted.

Explosive gas mixtures could be created if air is introduced into systems. If necessary, the system should be purged with an inert gas before introducing air. In all cases, a system should be purged with fresh air before it is entered.

Table 4-2. TROUBLESHOOTING CHART FOR ESP'S

	Symptom	Probable cause	Remedy
1.	No primary voltage No primary current No ESP current	DC overload condition	Check overload relay setting Check wiring and components
	Vent fan on	Misadjustment of current limit control	Check adjustment of current Limit control setting
		Overdrive of rectifiers	Check signal from firing circuit module
2.	No primary current No ESPcurrent Vent fan off Alarm energized	Fuse blown or circuit breaker tripped	Replace fuse or reset circuit breaker
		Loss of supply power	Check supply to control unit
3.	Control unit trips out an overcurrent when sparking occurs at high currents	Circuit breaker defective or incorrectly sized	Check circuit breaker
		Overload circuit incorrectly set	Reset overload circuit
4.	High primary current No ESP current	Short circuit condition in primary system	Check primary power wiring
		Too high ESP voltage for prevailing operating conditions	Lower the ESP voltage
		High-voltage circuit shorted by dust buildup between emitting & collecting electrodes	Remove dust buildup

Table 4-2 (continued). TROUBLESHOOTING CHART FOR ESP'S

Symptom	Probable cause	Remedy
	Slack or broken emitting electrode wire shooting the high "V" circuit	Deenergized ESP & remove or replace broken or slack wire
	Circuit component failure	Check transformer-rectifier & ESP: ground T-R high "V" connector to ESP
	Trouble in ESP	
	1) Dust buildup in hopper; check meters: - ammeter very high - kV meter very low (1/2 normal) - milliamperes very high	Clean off dust buildup
	2) Metallic debris left in unit during shutdown for maintenance	Deenergize ESP and remove
	3) Unhooked collecting plate touching emitting frame	Repair
	4) Broken support insulator	Repair
	5) Excessive dust buildup on hopper beams or cross member	Clean
5. Low primary voltage High secondary current	Short circuit in secondary circuit or pptr.	Check wiring and components in high voltage circuit; Check ESP for:

Table 4-2 (continued). TROUBLESHOOTING CHART FOR ESP'S

Symptom	Probable cause	Remedy
		Interior dust buildup Full hoppers Broken wires Ground switch left on Ground jumper left on Foreign material on high voltage frame or wires Broken insulators
6. Abnormally low ESP current and primary voltage with no sparking	Misadjustment of current and/or voltage limit controls	Check settings of current and voltage limit controls
	Misadjustment of firing circuit control	Turn to maximum and check setting of current and voltage limit controls
	Heavy coating on emitting electrode wires	Check emitting frame vibration and emitting vibration shaft insulator
	Stream of cold air entering ESP from defective door gasket duct opening, inlet gas system rupture - condensation	Repair
	Wet dust clinging to wires causes extremely low milliammeter readings	Eliminate source of condensation
	Severe arcing in the ESP without tripping out the unit	Eliminate cause of arcing
7. Spark meter reads high-off scale	Continuous conduction of spark counting circuit	Deenergize, allow integrating capacitor to discharge and re-energize

Table 4-2 (continued). TROUBLESHOOTING CHART FOR ESP'S

	Symptom	Probable cause	Remedy
	Low primary voltage and current		
	No spark rate indication	Spark counter counting 60 cycles peak	Readjust controls
8.	Spark meter reads high	Misadjustment	Readjust
	Primary voltage and current very unstable	Loss of limiting control	Replace control
9.	No spark rate indication voltmeter and ammeter unstable indicating sparking	Failure of spark meter	Replace spark meter
		Failure of integrating capacitor	Replace capacitor
		Spark counter sensitivity too low	Readjust sensitivity
10.	No response to voltage limit adjustment	Controlling on current limit or spark rate	None needed if unit is operating at maximum current or spark rate
	Does respond to current adjustment		Reset current and spark rate adjustment if neither is at max
11.	No response to spark rate adjustment	Controlling on voltage or current	None needed if unit is operating at maximum voltage or current
	Does respond to other adjustment		Reset voltage and current adjustment if neither is at max

Records

Accurate daily logs should be kept of all aspects of precipitator operation, including electrical data, changes in rapper and boiler operation, and variations in fuel quality. Such logs aid the preventive-maintenance effort by providing clues to probable causes for changes in performance.

Following the prescribed maintenance procedures and maintaining accurate logs will provide benefits that justify the effort.

4.2 UTILITY PROCEDURES AND RECORDKEEPING DURING STARTUP AND MALFUNCTIONS

4.2.1 Utility Startup Procedures

Upon restarting of a coal-fired boiler that has been out of service for a period of time, it is fired with oil or gas for 4 to 5 hours. During this time the pulverizers are turned on for about 5 minutes at a time until operation is sustained and stable; more than one mill is always run. About 8 hours is required to bring a unit on line, i.e. when the steam pressure reaches 2.8 MPa (400 psi); the turbines are then turned over. The ESP is not energized until the temperature reaches the design range, which is about 107-135°C (225-275°F) for cold-side ESP's. The precipitator is turned on manually, usually 1 hour after the unit is firing coal.

Times required to bring the boiler to proper operating temperature vary, but the described procedure is representative of that for a coal-fired boiler.

4.2.2 Utility Procedure and Recordkeeping During Malfunctions

Part 60 of Title 40, Code of Federal Regulations, Section 60.7, as amended, December 16, 1975, requires that a utility report excess emissions caused by malfunctions or other reasons by submitting a written report to the Administrator for each calendar quarter.[19] The report is to include the magnitude of excess emissions as measured by the required monitoring equipment, reduced to the units of the applicable standards; it is to give the date and time of commencement and completion of each period of excess emissions. Periods of excess emissions due to startup, shutdown, and malfunction are be be specifically identified. The nature and cause of any malfunction if known, the corrective action taken, or preventive measures adopted are to be reported. Each quarterly report is to be submitted by the 30th day following the end of the calendar quarter.

This section compares the methods of reporting ESP malfunctions practiced by two U.S. utilities. The reporting procedures of most other U.S. utilities probably encompass similar features.

In the case of the first utility, a reportable malfunction is considered to be any sudden or unforeseen malfunction of particulate control equipment that causes or could cause any of the utility's units to exceed specified limits for a period of 4 or more hours. When this occurs the following procedure is followed:

1. The malfunction is reported by phone or telegram to the EPA regional office and to state or local officials. The air quality branch of the utility is also contacted.
2. The plant superintendent submits a report to the EPA regional office, with copies to various branches of the utility. The report includes the following:
   a. Time and date excess emissions began and ended.
   b. Time and date the breakdown causing the excess emissions began and ended.
   c. Type of emission, estimated rate, and copies of the opacity monitor records.
   d. Cause of the malfunction.
   e. Operation and maintenance procedures, prior to and during the malfunction, designed to prevent such an occurrence.
   f. Additional steps taken to minimize the extent or duration of the malfunction.
   g. Future plans to minimize the possibility of similar malfunction.

Monthly records are kept, by plant and unit, of all malfunctions, total hours transformer-rectifier (T-R) sets are operated, number of hours T-R sets are not operating (broken down into 24 hours and >24 hour intervals), maximum number of sets out at one time, and the monthly/yearly availability of the ESP unit in percent. In addition, daily logs are kept on each ESP unit, with remarks on outages of various sections of the ESP. Costs for operation and maintenance on all ESP's are also tabulated.

With the second utility, an ESP is considered to be malfunctioning if opacity is 20 percent or greater. Therefore, an ESP could be operating at less than its design efficiency and still remain in operation. If 20 percent opacity is reached, EPA is subsequently notified, but the boiler and ESP are not taken out of service until the following weekend; the necessary maintenance is then performed. Corrective actions and preventive measures are reported to EPA in a brief letter, which may not be sent until a month or two after the malfunction has occurred.

4.2.3 Outages - Forced and Scheduled

Forced outages result from unpredicted malfunctions requiring immediate shutdown. Planned outages are scheduled for maintenance and inspection.

Forced outage malfunctions, by definition, involve shutdown and startup. Some malfunctions, however, can be resolved online and do not require a shutdown. In these instances boiler operation may be reduced to as low as 10 percent of design load without appreciably increasing emissions.

Planned outages require complete shutdown of the unit to enable maintenance personnel to perform such tasks as slag cleanout, ESP repair, and boiler tube repair.

4.3 COSTS OF COLD SIDE ESP MAINTENANCE AND OPERATION[20]

The annualized costs of maintenance and operation of 18 model cold-side ESP's have been estimated. These annualized costs are comprised of the following items:

> Utilities, including water for ash slurries and cleaning; electricity for fans, valves, lighting, controls, hoppers, rappers, and charge of plates.
>
> Operating labor, including supervisory and skilled and unskilled labor required to operate, monitor, and control the ESP.
>
> Maintenance and repairs, consisting of manpower and materials to keep the unit operating efficiently. The function of maintenance is preventive and corrective.
>
> Overhead, a business expense that is not charged directly to a particular part of a process but is allocated to it. Overhead costs include administrative, safety, engineering, legal, and medical services; payroll; employee benefits; and public relations.
>
> Fixed Charges, which continue for the estimated life of the system and include costs of the following:
>
> - Depreciation - the charge for losses in physical assests due to deterioration (wear and tear, erosion and corrosion) and other factors, such as technical changes making the physical assets obsolete.
> - Interim replacement - costs expended during the year for temporary or provisional replacement of equipment that has failed or malfunctioned.

- Insurance - costs of protection from loss by a specified contingency, peril, or unforeseen event. Required coverage could include losses due to fire, personal injury or death, property damage, embezzlement, explosion, lightning, or other natural phenomena.
- Taxes - including franchise, excise, and property taxes leveed by a city, county, state, or Federal government.
- Capital costs due to interest on borrowed funds.

4.3.1 Basis of ESP Annualized Cost Estimates for 18 Model Plants

The capital and annualized costs of electrostatic precipitators can vary significantly with design philosophy and site-specific factors. Factors having a major cost impact are plant size (capacity), remaining life, and capacity factor; sulfur and ash content and heating values of the coal; maximum allowable particulate emission rate; control system status (new plant or retrofit); and replacement power requirements.

As a means of illustrating the impact of site and process factors on total installed and annualized costs of ESP's, 18 model plants have been defined and cost estimates prepared for each. The coverage here is restricted mainly to annualized operation and maintenance costs. These estimates, presented in the following sections, are in January 1976 dollars and do not include escalation through project completion or replacement power.

The 18 model plants analyzed for ESP costs were selected to incorporate three factors that affect costs: plant size (capacity), installation status, and degree of particulate control required. Boiler capacities of 150 MW, 300 MW, and 450 MW were considered. Both new and existing ESP applications are considered for each boiler size. Each plant size is also analyzed in terms of three particulate control requirements: 94 percent control on Eastern high-sulfur coal and corresponding to a specific collecting area (SCA) of 640 (200); 99 percent control on Eastern low-sulfur coal, corresponding to an SCA of 1920 (600); and 99.9 percent (10% opacity) control on Western low-sulfur coal, corresponding to an SCA of 4570 (900). Specific collecting area (SCA) is the ratio of the area of the collecting plates in the ESP to the flue gas flow rate in thousands [$m^2/10^3 m^3$/min ($ft^2/10^3$ acfm)].

Other variables such as remaining plant life and plant capacity factor are selected to be representative of each model plant. Operating costs for such items as utilities, which vary with geographical location, are considered representative of a midwest location. Table 4-3 identifies the characteristics and major assumptions for the model plants. Table 4-4 presents the analyses of the coals used in the study. Table 4-5 gives capital costs for all 18 model plants.

Table 4-3. SUMMARY OF CHARACTERISTICS AND ASSUMPTION FOR MODEL PLANTS

Model plant parameters	Characteristics and assumptions			
Plant capacities, megawatts	150, 300, and 450 (single boilers)			
Plant status	Existing (retrofit) and new			
Particulate control requirement	Assumed levels of 99.0 percent control required on Eastern high sulfur coal 99.0 percent control required on Eastern low sulfur coal; and 99.9 percent control (10% opacity) required on Eastern low sulfur coal.			
Boiler data				
Capacity factor	Assumed 0.6 for all plants			
Heat rates, flue gas flow rates, and remaining life	Capacity MW	Heat rate[a], Btu/kWh	Flue gas[b] flow rate, acfm/MW	Remaining boiler life, yrs.
	150 existing	10,000	3,400	10
	150 new	9,300	3,200	35
	300 existing	9,500	3,275	15
	300 new	9,200	3,175	35
	450 existing	9,300	3,140	20
	450 new	9,200	3,080	35
Operating cost factors	Based on averages for midwest region			
Electricity cost	20 mills/kWh			
Taxes	4%			

[a] MJ/kWh = Btu/kWh × 1055.87 J/Btu $\div 10^6$ J/MJ

[b] m^3/min/MW = acfm/MW × $(\frac{0.3048\ m}{ft})^3$

Table 4-3 (Continued). SUMMARY OF CHARACTERISTICS AND ASSUMPTIONS FOR MODEL PLANTS

Capital cost	9%
Retrofit characteristics	Longer duct runs, tight space constraints, increased construction labor costs
Capacity derating	ESP - 0.5 percent Eastern coal 0 percent
Energy penalty	ESP - 0.5 percent
Replacement capacity cost	$400/kW

Table 4-4. COAL ANALYSES ASSUMED FOR ESP COST EVALUATION

Coal type	Sulfur content, percent	Ash content, percent	Heating value[a], Btu/lb
Eastern high sulfur	3.0	15	11,000
Eastern low sulfur	1.0	15	11,000

[a] $\text{MJ/Kg} = \text{Btu/lb} \times \frac{1055.87\ \text{J}}{\text{Btu}} \times \frac{\text{lb}}{0.4535924\ \text{Kg}} \div \frac{1000\ \text{J}}{\text{MJ}}$

Table 4-5. CAPITAL COSTS FOR ELECTROSTATIC PRECIPITATORS

Cost element	Plant size/capital cost								
	150 MW			300 MW			450 MW		
	\$, MM	\$/kW	\$ per ft^2 plate area	\$, MM	\$/kW	\$ per ft^2 plate area	\$, MM	\$/kW	\$ per ft^2 plate area
Existing Plants									
• Electrostatic precipitator @ 200 SCA	3.74	24.9	35.73	7.75	25.8	38.17	12.06	26.8	41.16
• Electrostatic precipitator @ 600 SCA	8.35	55.7	27.32	13.94	46.5	23.67	20.13	44.7	23.76
• Electrostatic precipitator @ 900 SCA	12.14	80.9	26.46	20.21	67.4	22.87	29.15	64.7	22.93
New Plants									
• Electrostatic precipitator @ 200 SCA	3.34	22.3	33.95	6.13	20.4	31.15	9.90	22.0	34.44
• Electrostatic precipitator @ 600 SCA	6.69	44.6	23.25	11.63	38.8	20.36	17.14	38.1	20.63
• Electrostatic precipitator @ 900 SCA	9.93	66.2	23.00	17.15	57.2	20.02	25.18	56.0	20.20

Metric conversion: SCA - 1 ft^2/10^3 acfm x 3.2 = 1 m^2/10^3 m^3/min.

4.3.2 Annualized Costs

Annualized costs for the 18 model plants are presented in Table 4-6. The annual costs in mills per kilowatt hour decrease as the size of the units increases for most cases. Costs for retrofit cases are higher because of the effects of the higher capital cost for retrofitting.

Table 4-6. ANNUALIZED COSTS FOR ELECTROSTATIC PRECIPITATORS

Cost element	Plant size/annual cost					
	150 MW		300 MW		450 MW	
	$, MM	mills/kWh	$, MM	mills/kWh	$, MM	mills/kWh
Existing Plants						
Electrostatic precipitator @ 200 SCA	1.11	1.41	1.98	1.25	2.83	1.19
Electrostatic precipitator @ 600 SCA	2.43	3.08	3.57	2.26	4.79	2.02
Electrostatic precipitator @ 900 SCA	3.50	4.44	5.15	3.26	6.91	2.92
New Plants						
Electrostatic precipitator @ 200 SCA	0.77	0.97	1.35	0.85	2.14	0.90
Electrostatic precipitator @ 600 SCA	1.50	1.89	2.57	1.62	3.75	1.58
Electrostatic precipitator @ 900 SFA	2.19	2.77	3.76	2.38	5.49	2.32

Metric conversion: SCA - 1 $ft^2/10^3$ acfm x 3.2 = 1 $m^2/10^3 m^3$/min.

5.0 INSPECTION TECHNIQUES FOR EVALUATING MAINTENANCE PROCEDURES

This section describes procedures for inspection of an ESP at a utility operating a coal-fired boiler. The circled numbers correspond to those on the example inspection checklist in Section 5.2.

5.1 TYPICAL ESP INSPECTION PROCEDURE

① Observe the plume before entering the plant[21]

Opacity of the plume is the most indicative guide to the performance of an ESP. If plume opacity is greater than it was under similar boiler load conditions at an earlier time, either the collection efficiency of the ESP has decreased or the fuel quality has decreased.

Determine the plume's equivalent opacity. (Do not mistake water vapor condensation for particulate emission.) Table 5-1 illustrates possible operating factors that may be causing a visible emission. If visible emissions exceed applicable standards, use the standard form and follow established procedures for recording the violation.

② Obtain basic boiler data or update boiler data from the previous inspection. Check for changes in fuel quality that might affect ESP operation and emissions.

Table 5-1. PLUME CHARACTERISTICS AND OPERATING PARAMETERS FOR COAL-FIRED BOILERS

Stack plume	Associated pollutant	Occurrence Coal	Possible operating factors to investigate
White	Particulate	common	Excessive combustion air
Gray	Particulate	common	Inadequate air supply or distribution
Black	Particulate	common	Lack of oxygen; clogged or dirty burners or insufficient atomizing pressure; improper coal size or type
Reddish-brown	Nitrogen dioxide	rare	Excessive furnace temperature, burner configuration, too much excess air
Bluish-white	Sulfur trioxide	rare	High sulfur content in fuel
Yellow or brown	Organics	rare	Insufficient excess air

(Source: Ref. 21)

③ Obtain or update general ESP data, noting any efficiency tests since the last inspection or changes in the operating parameters. Find out what operating problems the ESP has had. The plant should provide a diagram showing what fields are served by what transformers as a guide to determining what fields are out when reading ESP controls.

④ Check control set readings and compare with calibrated values for these controls. Many times problems that develop gradually can be recognized by small variations from normal. Check daily log to determine whether readings have been drifting from normal. Drift is indicative of such problems as:

a. Air inleakage at air heaters or in ducts leading to the ESP.

b. Dust buildup on ESP internals.

c. Deterioration of electronic control components.

If grossly abnormal readings are noted, they indicate a serious problem and can aid in diagnosing the probable cause. Following are some examples:

a. One section grounded out - A voltage drop will be observed in the precipitator (kV, d.c.), and primary transformer (V, a.c.). There will be an increase in the primary transformer amps (I, a.c.), in the average precipitator amps, (I, d.c.), and in the precipitator spark rate.

b. Ash buildup on wires and plates will reflect high amps.

c. A broken wire, not grounded, that is bouncing from one collecting plate to another would show a decrease in precipitator voltage (kV, d.c.), the transformer primary voltage (V, a.c.), would increase. Also, the needles will bounce as the wire travels from one collecting plate to another.

d. A broken wire to the insulator (shorted out) will be most noticeable if the T-R set is on full wave. The primary transformer amps (I, a.c.) will decrease, precipitator average amps (I, d.c.) will decrease, transformer primary voltage (V, a.c.), will increase, and precipitator voltage (kV, d.c.) will increase.

Typical ranges of ESP control readings for proper operation are given below:

	minimum	maximum	typical
1. Primary voltage, volts			460/480 ± 5%
2. Primary current, amps	50	200	125
3. ESP voltage kilovolts	30	100+	40-65
4. ESP current milli amps	250	1500+	750
5. Spark rate/min	10	100+	75

It may be difficult to determine whether a section is out by reading the ESP controls. You may need the help of the utility's malfunction records to determine which sections are experiencing problems.

⑤ Check pressure drops through the system and compare with the normal pressure drops.

⑥ Check ash hoppers for proper operation. Determine the interval between hopper cleanouts. Check hopper skin temperature with the back of your hand. Comparatively low temperature of one or more hoppers could indicate a malfunction of the ash removal system, causing bridging or plugging of the hoppers and subsequent ash buildup.

⑦ If possible, check the precipitator control room and make sure that ventilation is adequate; check control sets internally for dirt, which can cause false signals and cause components to deteriorate.

⑧ If possible, check insulators for signs of deterioration such as moisture and tracking from arc-over. Make sure air filters to control sets and top housing are not plugged.

⑨ If possible, check rapper action visually and confirm vibrator operation by feel. You will not be able to tell whether all of the rappers are operating properly unless you know the sequence of rapping action.

⑩ Check exterior of ESP for corrosion, loose insulation, exterior damage, and loose joints. Give special attention to points where gas can leak, causing fugitive emissions.

⑪ Review operating records for all aspects of precipitator operation including electrical data, changes in rapper and boiler operation, and variations in fuel quality.

Table 5-2 lists recommended recordkeeping requirements. These records can provide clues to probable causes of changes in performance. Malfunctions since the last inspection should be evaluated. The inspector should spot-check these records to ensure that the plant is adhering to proper operating procedures between inspections.

Table 5-2. RECOMMENDED RECORDKEEPING REQUIREMENTS

Item	Frequency	Comments
ESP Controls		
Instrument calibration	Initial measurement	Compare daily measurements with red-lined readings. Check for gross misreadings or slow drift from redline.
Primary current, A	Daily	
Primary voltage, V	Daily	
Operating current, mA	Daily	
Operating voltage, kV	Daily	
Spark rate, sparks/min	Daily	
Pressure drop through system, in.	Daily	Compare with initial pressure drop measurement
Rapper operation	Daily	Check frequency and intensity
Insulator condition	Daily	Check for deterioration
Fuel quality	Monthly	State range of values and average
Sulfur, %		
Ash, %		
HHV, Btu/lb		
Changes in boiler operation	As occurring	
Flue gas analysis, % by vol. (Circle CO_2 or O_2)	Spot checks	
Soot blowing intervals	Daily	State hours or blows per day
Malfunctions	As occurring	Use standard form for describing malfunctions

⑫ Estimation of ESP control efficiency

Use design or, preferably, test efficiency after ascertaining that present operating conditions are consistent with design or test conditions (e.g., boiler load, ash and sulfur contents of coal, precipitator operating temperature). If such data are not available, perform the following calculation:

Read secondary currents and voltages for each field of the precipitator.

Calculate delivered corona power for each section according to the following formula:

Delivered power = (secondary voltage) x (secondary current)

If there are no meters for secondary voltage and current, calculate delivered power for each precipitator field as follows:

Delivered power = (input power) x (power supply efficiency)

Input power = (primary current) x (primary voltage)

Typical power supply efficiency is 90 percent.

Determine total corona power input by summing the delivered power for each section.

Calculate corona power input per 10^3 m^3/sec (10^3 ft^3/min) of flue gas (i.e. watts per 10^3 m^3/sec (10^3 ft^3/min).

Obtain precipitator collection efficiency value from Figure 5-1.

If power data are not available from meters on the precipitator power supply panel, perform the following calculation:

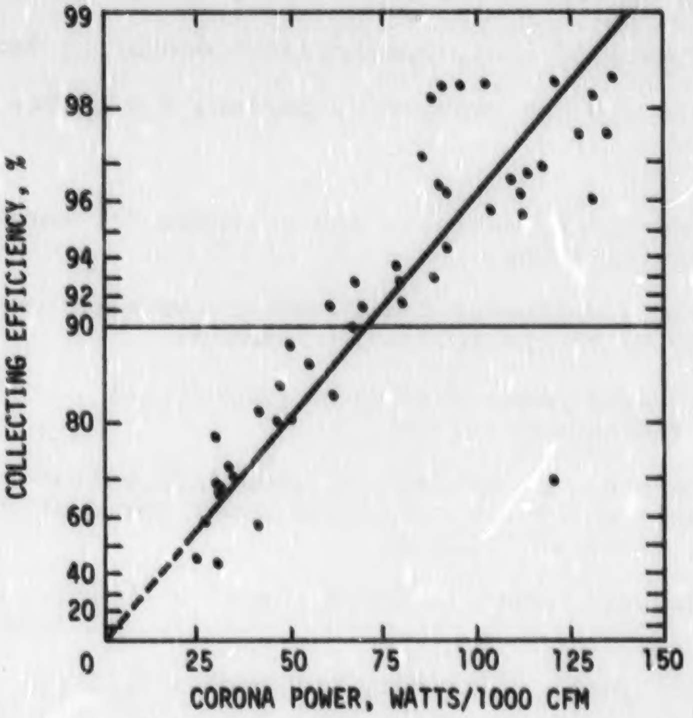


Figure 5-1. Electrostatic precipitator collection efficiency vs. delivered power.

Metric conversion: $w/10^3 m^3/min = w/10^3\ ft^3/min \div 0.028$

Determine total square feet of precipitator collecting area (plate area) from manufacturer's specifications.

Obtain sulfur content of coal being burned from operator.

Use these values to determine expected collection efficiency from Figure 5-2.

Actual emissions. Actual emissions are computed according to the following formula.

$AE = (UE)(100-E)$

where:

AE = actual emissions [(kg/hr) (lb/hr)]
UE = uncontrolled emissions [(kg/hr) (lb/hr)]
E = control device efficiency, percent

⑬ Comments

Use this section for describing items too long to be entered on the form, such as deficiencies found during the inspection and malfunctions occurring since the last inspection.

The results of the inspection could also be summarized here. A copy of the entire checklist could be sent to the utility with a letter that confirms that the inspection was made, states any deficiencies, asks that they be corrected, and makes recommendations for further improvement in operation and maintenance of the ESP.

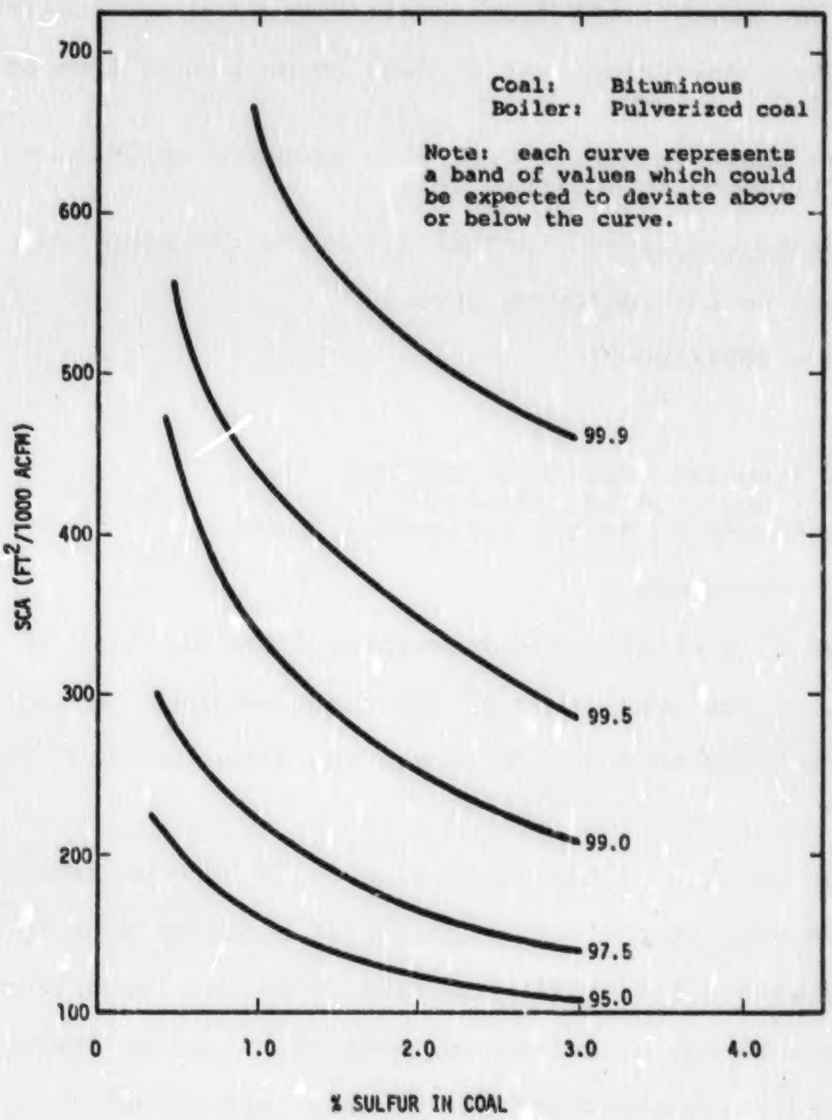


Figure 5-2. Cold-side ESP.

SCA vs. % S

Metric conversion: SCA - 1 ft^2/10^3 acfm x 3.2 = 1 m^2/10^3 m^3/min

5.2 INSPECTION CHECKLIST FOR ELECTROSTATIC PRECIPITATORS IN THE ELECTRIC UTILITY INDUSTRY

FACILITY IDENTIFICATION

Facility Name: ______________________________

Facility Address: ______________________________

Inspection Date: ______________________________

Person to Contact: ______________________________

Source Code Number: ______________________________

PREINSPECTION DATA SHEET

Adequate information

Inadequate information (Obtain needed data during first inspection)

① PREENTRY DATA

Stack Plume - **Equivalent Opacity** (Circle one): 0 20 40 60 80 100

Opacity regulation

In compliance Not in compliance

Smoke

White Grey Black or Brown

Reddish Brown Bluish White Yellowish Brown

② BOILER DATA

a) Service: Baseload, standby, floating, peak:

b) Total hours operation (19__):

c) Average capacity factor (19__):

d) Year boiler placed in service:

e) Generating capacity (MW):

f) Served by stack No.:

g) Fuel consumption:
Coal Mg/yr (ton/yr)
Oil m^3/yr (bbl/hr)
Gas mcm/yr (mcf/hr)

Primary fuel composition: Circle one
Coal
Oil
Gas

Range	Average
Ash _______% to ____%	______%
Sulfur ____% to ____	______%
J/Kg (Btu/lb) _____ to _____	_______
J/l (Btu/gal) _____ to _____	_______
J/m^3 (Btu/ft^3) ____ to _____	_______

③ ELECTROSTATIC PRECIPITATOR - GENERAL DATA

ESP No.:

Manufacturer:

Type:

Efficiency (Design/Actual):

Mass emission rate:

g/acm (gr/acf)
Kg/hr (#/hr)
Kg/MJ (#/MM Btu)

No. of cells or individual bus sections:

No. of fields:

No. of cells:

Total plate area:

Flue gas temperature @ inlet to ESP @ 100% load °C (°F):

Stack diameter:

Stack height:

Stack gas exit temperature:

④ CONTROL PANEL READINGS

Present operating voltage	Calibrated operating voltage	Present operating current	Calibrated operating voltage	
________	________	________	________	Field 1
________	________	________	________	Field 2
________	________	________	________	Field 3
________	________	________	________	Field 4
________	________	________	________	Field 5
________	________	________	________	Field 6

Spark rate: __________ Sparks/min.

⑤ AIR FLOW READING

Pressure before ESP _____________ Pascals (in) H_2O

Pressure after ESP ______________ Pascals (in) H_2O

⑥ HOPPERS

Interval between hopper cleanouts _____ hours.

	Satisfactory	Unsatisfactory
Cleanout and transport procedure	☐	☐
General housekeeping	☐	☐

⑦ CONTROL ROOM

	Satisfactory	Unsatisfactory
Ventilation	☐	☐
Control sets condition	☐	☐

⑧ CONDITION OF INSULATORS

⑨ RAPPER OPERATION

⑩ ESP EXTERIOR CONDITION

⑪ MAINTENANCE AND OPERATIONS

Records Kept:

	Yes	No
Instrumentation calibration	☐	☐
Collector control readings	☐	☐
Fuel analysis, changes in quality	☐	☐
Pressure drop through system	☐	☐
Rapper operation, changes	☐	☐
Boiler operation, changes	☐	☐
Flue gas analysis	☐	☐
Soot blowing intervals	☐	☐
Malfunctions	☐	☐

⑫ ESTIMATION OF ESP EFFICIENCY

	Kg/hr (lb/hr)	g/scm (gr/scf)	Kg/MJ (lb/MM Btu)
Uncontrolled emissions			
Actual emissions			

Control device efficiency __________%

⑬ COMMENTS

REFERENCES

1. Oglesby, Sabert, Jr. A Manual of Electrostatic Precipitator Technology. Southern Research Institute, Birmingham, Alabama. August 25, 1970.

2. White, Harry J. Industrial Electrostatic Precipitation. Addison-Wesley. 1963.

3. The Electrostatic Precipitator Manual. The McIlvaine Co. Copyright 1976.

4. Walker, A. B. Characteristics and Electrostatic Collection of Particulate Emissions from Combustion of Low-Sulfur Western Coals. Research-Cottrell, Inc. (Paper 74-11, presented at Air Pollution Control Association 67th Annual Meeting. Denver, June 9-13, 1974).

5. Walker, A. B. Experience with Hot Electrostatic Precipitators for Fly Ash Collection in Electric Utilities. Research-Cottrell, Inc. (Presented at American Power Conference. Chicago, April 29-May 1, 1974).

6. Schneider, Gilbert G., et al. "Selecting and Specifying Electrostatic Precipitators." Chemical Engineering. May 26, 1975.

7. Matts, S. and P-O ohnfeldt, "Efficient Gas Cleaning with SF Electrostatic Precipitators."

8. Industrial Gas Cleaning Institute, Inc., "Terminology for Electrostatic Precipitators."

9. Hesketh, Howard E., and Frank L. Cross, Jr. Handbook of Air Pollution Control Equipment.

10. Aimone, R. J. et al. "Experience with Precipitators when Collecting Ash from Low-Sulfur Coals," presented at the 36th annual meeting of the American Power Conference, Chicago, Illinois. April, 1974.

11. Dismukes, E. B. "Conditioning of Fly Ash with Ammonia," Southern Research Institute, presented at the Symposium on Electrostatic Precipitators for the Control of Fine Particles, in Pensacola Beach, Florida. September 30-October 2, 1974.

12. Busby, H. G. T., and K. Darby. Efficiency of Electrostatic Precipitators as Affected by the Properties and Combustion of Coal. J. Inst. Fuel (London). 36:184-197. May, 1963.

13. Dismukes, E. B. A Study of Resistivity and Conditioning of Fly Ash. Southern Research Institute, Contract CPA 70-149, Environmental Protection Agency. Publication Number EPA R2-72-087. February, 1972. NTIS PB 212607. 138 p.

14. Dalmon, J. and D. Tidy. The Cohesive Properties of Fly Ash in Electrostatic Precipitation, Atmos. Environ. (Oxford, England), 6:81-92, February, 1972.

15. Dismukes, E. B. Conditioning of Fly Ash with Sulfur Trioxide and Ammonia. Southern Research Institute for Environmental Protection Agency and Tennessee Valley Authority. 1975.

16. Dismukes, E. B. Conditioning of Fly Ash with Sulfuric Acid, Ammonium Sulfate, and Ammonium Bisulfate. Southern Research Institute, Contract No. 68-02-1303, Environmental Protection Agency. October, 1974.

17. Bump, Robert L. "Electrostatic Precipitator Maintenance Survey," TC-1 Committee of Air Pollution Control Association.

18. Bibbo, P. P., and M. M. Peacos. "Defining Preventative-Maintenance Tasks for Electrostatic Precipitators, Research Cottrell, Inc., Power, August, 1975. pp. 56-58.

19. Federal Register, part 60 of Title 40, Section 60.7 as amended December 16, 1975.

20. PEDCo-Environmental Specialists, Inc., "Electrostatic Precipitator Cost Study," prepared for Division of Stationary Source Enforcement, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. August, 1976.

21. Devitt, Timothy W., Richard W. Gerstle, and Norman J. Kulujian. "Field Surveillance and Enforcement Guide: Combustion and Incineration Sources." PEDCo-Environmental Specialists, Inc. June, 1973.

APPENDIX A

ESP MANUFACTURERS SUGGESTED MAINTENANCE PROCEDURES

Guidelines for ESP maintenance from five manufacturers have been evaluated in compilation of a list of typical recommended maintenance procedures for all types of ESP's. These procedures, typical of those the manufacturer presents to the purchaser of a new ESP, include the following categories:

A.1 Description of major ESP components and general maintenance

A.2 Preliminary or preoperational checkout and testing

A.3 Startup

A.4 Routine of preventive maintenance on a daily, weekly, monthly, quarterly, and annual basis.

A.1 DESCRIPTION OF ESP COMPONENTS AND GENERAL MAINTENANCE

A.1.1 Gas Distribution System

A gas distribution system, composed of one or more rows of distribution plates, is located in the inlet duct immediately before the ESP. This distribution system ensures that an even flow of dust-laden gas enters the precipitator, thus providing optimum operating efficiency.

A.1.2 Precipitator Shell

Combustion of coal usually produces a small amount of SO_2 and SO_3 as well as CO_2, O_2, and moisture. The traces of

SO_3 can cause fairly rapid corrosion of the interior of gas ducts, fans, and dust-collecting equipment if these interior surfaces become cool for any reason. It is therefore recommended that thorough internal inspection be made during the first year of operation. If interior corrosion is noted, some means of correction should be applied as soon as possible. Applying heat insulation to exteriors of the corroded components will normally correct this condition. In installations where the boiler periodically operates at low loads, covering the interior surfaces of side frames, end frames, and roof with gunite will prevent any corrosive damage to the steel.

A.1.3 Collecting Plates

The gas flows horizontally in the precipitator through individual gas ducts formed by the collecting plates. The discharge electrodes are located midway between the plates for the purpose of ionizing the gases and imparting an electrical charge to the dust particles. It is important that the plate and electrode spacing be held to close tolerances. If not, close clearances can cause high localized sparking, which reduces the maximum precipitator voltage and thus the collection efficiencies.

Whenever the precipitator is out of service and internal inspections are possible, the collecting plates should be checked for proper alignment and spacing. Hangers should be checked, and spacers at the bottom of the plates should not bind plates to prevent proper rapping. The lower portions of all plates and the portion of plate adjacent to any door opening should be checked for signs of corrosion. Corrosion usually is indicative of air inleakage through hoppers or around doors. Causes of such inleakage should be repaired at once.

At each inspection, the dust deposits on the collecting plates should be observed before any cleaning of the precipitator is started. The normal thickness of the collected fly ash should be about 3.2 mm (0.125 in), with occasional buildups to 6.4 mm (0.25 in). If the buildup exceeds this amount, the intensity of the plate rappers should be increased. If the collecting plates are almost metal clean, however, the lack of dust buildups may indicate high gas velocity, extremely coarse fly ash, or an operation voltage too low for good precipitation. This condition may be noted if a section has been shorted out prior to the inspection.

A.1.4 Discharge Electrodes

The discharge electrodes are small-diameter wires suspended from a structural steel wire supporting frame, held taut by individual cast iron weights at the lower end and stabilized by a steadying frame at the top of the cast iron weights. Whenever possible, the condition of the discharge electrodes should be checked with regard to dust buildup. The amount of buildup will indicate whether the high-tension vibrators, when furnished, are operating at the proper intensity.

The discharge electrodes should be perfectly centered between the plates from top to bottom for optimum precipitator operation. Any broken discharge electrodes should be removed and, if time permits, replaced with new wires.

A.1.5 Rapping Equipment

The purpose of the rapping or vibrating equipment is to dislodge the collected material from plates and/or wires before the accumulation becomes so heavy that it interferes with electrical operation. The "Operation and Maintenance Manual" supplied by the seller for each installation provides complete descriptions and instructions for operation and maintenance of the rapping equipment and their controls.

A.1.6 Hopper Emptying

It is extremely important that a regular schedule of hopper emptying be established at the start of operation and followed as closely as possible, preferably once each shift. If the hoppers are allowed to fill over a 24-hour period or longer, electrical components may short out and precipitation will cease. Also, if a fly ash hopper is allowed to stand for more than 24 hours, the dust tends to pack, cool, and absorb some moisture from the gases. The dust is then extremely hard to remove, and the moisture can start corrosion of the hopper steel. Dust often tends to build up in the upper corners of the hoppers, especially if they have been filled completely at any time. Any abnormal buildups should be removed. If this condition becomes chronic, it is an indication of low operating temperatures, insufficient heat insulation, or inadequate hopper emptying. Heat tracing of the hopper will usually correct this condition. In any event, scheduled hopper emptying is critical to efficient ESP operation.

A.1.7 Insulator Compartments or Housing

The insulator enclosures are vented with air to prevent flue gases from entering this space, which houses the supporting insulators. If the precipitator is under negative pressure, the air is admitted through open vents in the housing sides. If it is under positive pressure, the ventilating air is introduced by means of a ventilating fan, sized to maintain a pressure within the housing slightly higher than the precipitator pressure. This air flows downward around the inside of the bushings, which separate the treating zone from the insulator enclosures; the flow of air prevents the gases from entering these cooler enclosures and condensing on the interior surfaces and also helps keep the insulators clean. The interior condition of the enclosures should be carefully noted. All insulators should be cleaned and the exterior and interior of the bushings cleaned if necessary. The interior of the bushings can be cleaned easily with an air lance. The interior surfaces of the enclosures should be carefully inspected for signs of corrosion. Signs of corrosion or an abnormal buildup of dust in the enclosure can indicate insufficient ventilation. All high-tension connections to the bus beams should be checked to see that all connections are secure. If heaters are provided, they should be serviced as described in the maintenance manual for insulator compartment heaters.

A.1.8 Transformer-Rectifier Power Supply

a. The transformer-rectifier power supply is contained in an oil-filled tank and consists of the following equipment:

1. High-voltage supply transformer.
2. Silicon rectifier assembly.
3. Inductor in series with the high-voltage output bushing.
4. Low-voltage bushing for primary supply.
5. Metering and d.c. ground connection.

The transformer rectifier tanks are maintained by checking for leaks and for proper oil level; if Askarel is used as the dielectric, any spills must be cleaned up carefully because Askarel is flammable.

A.2 PRELIMINARY CHECKOUT AND TESTING

1. Check the line voltage for proper phase and magnitude.

2. Inspect the transformer-rectifier tanks for any signs of oil leakage or physical damage. Check the oil tank gauge and refill if necessary. Follow manufacturer's instructions for pertinent information. DO NOT OVERFILL THE OIL TANK.

3. Inspect the dust-conveying equipment and the hopper discharge valves.

4. Inspect main exhauster (if applicable).

5. Follow the procedure outlined under "Key Interlock System" to gain access to the precipitator.

6. Inspect the rapper motors prior to and during the initial equipment startup for proper rotation and alignment.

7. Inspect any gear motor that has been mechanically serviced for proper rotation and alignment.

8. Check the position of each collecting surface rapper hammer. These hammers must be in a position that conforms to the normal function of the hammer shaft. A hammer that has been manually tripped in advance of its normal function may cause damage upon gear motor startup.

9. Inspect the precipitator control cabinets and the transformer-rectifier for evidence of loose connections.

10. Inspect the precipitator chamber for foreign material, such as tools, rags, cleaning material, etc.

11. Disconnect the high-voltage conductor at the support insulator and check the discharge wires to ground prior to initial startup. Resistance to ground should be 100 megohms or greater.

12. Check the condition of all explosion relief doors (if applicable).

13. Check all access doors for operation and alignment and then lock them. Return the door keys to their proper location in the key interlock transfer block.

14. Operate the insulator heaters a minimum of 2 hours before energizing the precipitator. The ammeters on the heater control panel should be balanced and should read the equivalent of approximately 4kW/ line voltage.

    a. For a precipitator operating with positive pressure, the pressurizing fan(s) must be started prior to starting the main exhauster.

    b. The high-voltage heaters should not be turned off until after the precipitator has reached operating temperature.

    c. Energize precipitator.

A.3 STARTUP

1. Switch on the dust-handling system.

2. Switch on the discharge electrode and plate rapping systems.

3. Switch on the precipitator control circuit breaker.

    a. Allow precipitator high-voltage insulator heaters to warm up before switching on high voltage.

       Possible explosions are avoided by not switching on the high-voltage power while a combustible mixture is in the precipitator.

4. Place the precipitator power supply on automatic and press "ON" button.

A.4 ROUTINE PREVENTIVE MAINTENANCE

A program for maintaining the precipitator and its auxiliary equipment is recommended to ensure proper operation of the unit and to prevent outages caused by lack of maintenance.

Inspection of the unit on a daily, weekly, monthly, quarterly, and annual schedule is recommended. Data sheets and instructions supplied to the customer are of a recommended format, which may be altered by the customer to suit specific conditions. Following is a typical list of maintenance procedures that an ESP manufacturer might provide.

A.4.1 Daily

Control House

1. Check all precipitator control panels for vent fan operation.
2. Note conditions of filters on control panels.
3. Take precipitator control panel readings.
4. Maintain a daily log for reference.

Auxiliary Control Panels

1. Check insulator heaters for operation mode.
2. Record ammeter readings of each insulator heater.
3. Check all "Push to Test" lights on panel, replace as necessary.
4. Check all selector switches for proper operation in manual and automatic mode.
5. Check all rapper timers for operation. Rapper "on" time and "off" time is set by the service engineer and should not be changed except by authorized plant personnel. If times are readjusted, this should be noted on maintenance records. Record initial settings and final settings.
6. Test annunciator panel for operation. Replace any bad lights as necessary.

Precipitator

Dust Removal Level

1. Check hopper/dust-removal equipment for operation or signs of leakage. Record any faulty areas.

Side Access Level

1. Collecting Surface Rapper Drives

    a. Check all collecting surface rapper drive motors and reducers; note any leakage of reducer lubricant.

    b. Check all couplings for adequate lubrication.

    c. Check for operation temperature of reducer and motor. If rapper drive is operating, listen for rapping sound of hammers.

    d. Check any auxiliary equipment on this level.

Gas Inlet Level

1. Gas Distribution System Rapper Drives if equipped - same procedure as side access level.

Roof Level

1. Transformer-Rectifier

    a. Check all units for proper oil level. See instruction book for type, amount, and method of adding oil, if necessary.

    b. Record transformer-rectifier oil temperature.

    c. Note and report any leaks on tank of transformer-rectifier. If dielectric is Askarel (G.E. - Pyranol - Westinghouse - Inerteen), the manufacturer should be contacted immediately and extreme caution should be taken in cleanup of spill. See instruction book concerning handling of Askarel dielectric material.

Discharge Surface Rapper Drives

1. Check all discharge surface rapper drive motors and reducers. Note any leakage of reducer lubricant.

2. Check for operational temperature of reducer and motor.

3. Check all couplings for adequate lubrication.

4. Inspect each discharge surface cam drop mechanism for wear and operation. Check all rollers on cam drops for binding or restriction of movement when they drop off cam. If roller slides down face of cam, roller must be adjusted or disassembled and cleaned to eliminate this condition.

A.4.2 Weekly

1. Clean all insulators.

2. Check access doors for tightness.

A.4.3 Monthly

1. Check grounding switches on rapping cubicle doors and lubricate gate switches.

2. Check that safety interlocks operate freely.

3. Check rapping chains for slackness and grease.

4. Check rapping gear boxes and lubricate cam tips.

5. Check electrical contacts and connectors in the high-voltage control panel.

6. Check sealing bellows on connector drop rod rappers.

A.4.4 Quarterly

Control House

A. Precipitator Controls and Auxiliary Control Panels

1. Clean inside all panels.
2. Check all electrical components for signs of overheating.
3. Check for loose electrical connections.
4. Lubricate all door latches and adjust as necessary.
5. Check relays for freedom of movement.
6. Check vent fan for operation and check clearances between blades and shroud.
7. Install new air filters in control panel.

Side Access Level

A. Collecting Surface Rapper Drives

1. Check reducer for leaks.
2. Check coupling for signs of excess wear.

A.4.5 Annual

1. Remove dust buildup on wires and plants, if any.
2. Adjust vibrator and/or rapper intensity and cycle to prevent serious material buildup.
3. Inspect perforated diffuser screen and breeching for dust buildup.
4. Perform maintenance and lubrication of pressurized fans; check for leaks in the pressurized system.
5. Check for loose bolts in frames, verify that suspension springs are in good order, and examine wearing parts, hammers, anvils, etc.

6. Inspect discharge wires for tightness and signs of burning, and discharge system for correct alignment, broken parts, and welds.

7. Clean lead through insulators on underside.

8. Check all insulators for cracks.

9. Check complete collector grounding bonding wires and connections.

10. Drain oil, wash out, and refill gear boxes.

11. Check transformer fluid and dielectric strength.

12. Check relays, contactors, and starter contacts.

A.4.6 Recommended Spare Parts

Following is a typical list of spare parts recommended by manufacturers.

- support insulator/gaskets
- shaft insulator
- emitting electrodes
- H.V. bushings
- emitting electrode weights
- cap and pin insulators
- H.V. resistor assembly
- Lamp bulbs
- contractor operating cord and contact set
- shunts
- diodes
- filter circuit
- transformers
- relays
- capacitor
- silicon diode
- potentiometer
- resistors
- fuses
- printed circuit card

APPENDIX B

UTILITY ESP MAINTENANCE PROCEDURES

This section presents an example of a conscientious ESP maintenance procedure for utilities. Although this level of ESP maintenance is not practiced by all utilities, neglect of proper maintenance can lead to degradation of performance and ultimately to higher maintenance costs. These procedures are considered reasonable and representative of sound ESP maintenance practices for utility applications.

B.1 ASH REMOVAL SYSTEM

The document, "Operating and Maintenance Instructions," prepared by the Allen-Sherman-Hoff Co., Inc., provides detailed instructions for operation and maintenance of the ash-handling system. Operators of this equipment should be thoroughly familiar with information given in their manual and with the following supplementary items, required to ensure successful operation and maintenance of the ash removal equipment.

1. Obtain from the manual the recommended values of settings for timers, water pressure and flow, air pressure, and vacuum high and low settings.
2. Determine that compressed air supplied to this system is clean and moisture free.

3. Values assigned to settings for timers and vacuum high and low settings are theoretical and are listed as a starting point. Therefore, some field adjustment may be required for optimum operation.

4. Observe the air separator tanks overflow at least once weekly, since this may signal restricted ash slurry flow.

5. Give particular attention to vacuum highs and lows observed, since these readings will help in detecting worn hydrovactors and excessive air leakage.

6. At least once each day, determine whether each ash hopper is emptying and whether all control panel indicator lights are working. This can be accomplished by observing the panel lights, locating each hopper on the vacuum recorder sheet and looking for abnormal deviations in operation, and by touch to determine whether a hopper is full, empty, or evacuating ash at the appropriate time.

7. During outages, refer to the maintenance section of the manual and perform the preventive maintenance recommended.

B.2 ELECTROSTATIC PRECIPITATOR INSPECTION AND MAINTENANCE

B.2.1 General

To keep abreast of current operating problems and internal faults, review precipitator operating logs daily. This will ensure cognizance of unusual conditions and will expedite inspection and repair procedures, especially during emergency outages.

To maintain optimum collection efficiencies, it is essential that internal faults be corrected at the first unit outage following their discovery. External faults can be corrected as they occur.

If the plant staff cannot determine the reason for a fault, request immediate assistance from the central office. Any unusual condition or equipment problems should also be brought to the attention of the central office staff.

Make a thorough inspection of each precipitator during each scheduled outage and summarize the findings and corrective actions in the outage report. To facilitate the detailed inspection it is usually necessary to wash down the precipitator internals. If this is not done, it is almost impossible to inspect all components because of the fly ash buildup on the internals.

B.2.2 Clearance Procedures

Follow established clearance procedures in tagging out and placing grounds on the precipitator before any inspection or maintenance work is performed.

When a unit is shut down, keep the precipitator plate and wire rappers and ash-removal system in service for 24 hours to ensure that all loose dust is removed. During short outages it may not be possible to adhere to this procedure because of maintenance work inside the precipitator.

B.2.3 Insulator Heaters

Do not turn off the insulator heaters until the insulators have been wiped clean of fly ash accumulation. Otherwise, the accumulated ash will become sticky from absorbed moisture and will form a conductive path to ground. Also, once the ash has absorbed moisture it is very difficult to remove. If the heaters have been turned off following cleaning of the insulators during an extended outage, they should be energized at least 24 hours prior to firing the unit to ensure that they are dry and above the acid dewpoint. A conductive path across an insulator assembly could result in a catastrophic failure of the insulator from a high-voltage flashover.

B.2.4 Removal of Foreign Materials

Remove all scaffold boards and other foreign material from the precipitator before it is released for service.

B.2.5 Prestart Tests

Conduct air load tests following maintenance work on the precipitator to ensure that all sections are clear of grounds and alignment is satisfactory. During the air load test, increase the voltage slowly on manual control to preclude severe arc-over, which could damage an insulator. Compare data with initial and previous air load data.

During unit startups place the ash-removal system in service before a coal fire is established. Energize the precipitator as soon as possible after the pulverizers are placed in service. Each plant should determine optimum time for energizing the precipitators and prepare appropriate operation instructions.

B.2.6 Inspections and Maintenance During ESP Operation

Inspection and maintenance of components such as those in the penthouse of the precipitators may be done with the unit in service/ Work in any section of the caged area will require deenergizing and grounding of the transformer-rectifier set serving that section. Since each transformer-rectifier serves at least two bus sections, at least two bus sections must be out. If the remaining sections of the precipitator are in service and at their normal operating level of 40 kV or above, particulate emission limits can be met provided unit loads do not exceed the recommended limit. The high-voltage section must be grounded when inspecting the second or third fields because, even though these are deenergized, they can pick up a significant static charge from the upstream fields.

B.2.7 Critical Components - Caged Area

Inspect and maintain the critical components in the caged area on a routine basis. These include the upper portion of the insulators, insulator heaters and thermostats, high-voltage support insulators, high-voltage bus standoff insulators, voltage dividers, and the plate and wire rapper machanism. It is very important that the insulator heaters and thermostats be kept in good working order since their failure could result in tracking and insulator failure during operation at low gas temperature. Attention shall always be given the following:

a. Wipe insulators clean and inspect for cracks and air infiltration through the asbestos sealing rings.

b. Wipe high-voltage support and standoff insulators clean and inspect for cracks or evidence of tracking.

c. Check plate and wire rapper drive shaft bearings, drive motors, speed reducers, and chains and sprockets to ensure that they are properly lubricated.

d. Examine rapper cams and lift plates for wear and inspect the wire rapper shaft insulator for cracks; wipe clean.

e. Check resilient bellows seals on the wire and plate rappers for cracks and evidence of air infiltration; replace as needed.

f. Clean voltage dividers and examine for oil leakage.

B.2.8 Critical Components - Outside Caged Area

Critical components outside the caged area include the transformer-rectifier sets and their control cabinets and the rapper and insulator heater control cabinets. To ensure optimum performance of the precipitator controls, a plant electrician who is familiar with the precipitator controls should inspect them daily and make any required adjustments. This requirement is necessary to detect problems such as excessive sparking that are not evident from the daily operating logs.

B.2.9 Inspections and Maintenance During Shutdowns

B.2.9.1 Short Emergency Outages - Internal ground faults in a section that indicates high amperes and zero or very low voltage on the control panels are usually due to broken discharge electrodes, ash hopper buildup, or bridging of ash between the high-voltage frames and the collection plates. Such faults can also occur from cracked high-voltage insulators or from debris such as welding rods or pieces of wire that are left inside the precipitator during maintenance. These faults should be corrected during short emergency outages.

Cut broken wires at the unbroken end and remove them. Replacement of a cracked or failed insulator will required placing that section on temporary suspension. Check the alignment of this section following replacement of the insulator and removal of the section from temporary suspension. Minimum and maximum distances between the high-voltage frames and the collection plates are shown in the manufacturer's handbook.

Install the asbestos sealing rings in the insulators with care to ensure a good seal and prevent the inleakage of air, which will result in internal corrosion. The insulator assembly is shown in the manufacturer's handbook.

Clean all insulators if time permits. If there is sufficient time after completion of the work mentioned, inspect other sections of the precipitator. Look for indications of electrical tracking; air infiltration; unusual accumulations of dust on the plates and wires, which may indicate ineffective rapping; misalignment; loose bolts, particularly on the center mast brace assemblies and rapper anvils; and any indications of corrosion or distress on the precipitator internals. Document the results of each inspection to aid in future inspections and planning for maintenance work.

B.2.10 Long Scheduled Outages

B.2.10.1 Prewash Inspection - Inspect the precipitator internals as soon as possible after the unit comes off the line before it is washed. Note any unusual dust accumulations; polished areas, which indicate gas bypassing; swept areas, which may be the result of air infiltration; and other items that may require significant repair work. Arcing between the wire mast and the high-voltage support frame resulting from loose bolts is shown by dark spots in the fly ash adhering to these areas; such spots can readily be seen before the precipitator is washed. Wipe insulators clean before washing. After cleaning the insulators, shut off the heaters to preclude grounding during washing or possibly breakage of heater insulators from cold raw water impingement. This work can usually be done while preparations are being made to wash the precipitator.

B.2.10.2 Washing - Thoroughly wash down the precipitator internals with raw water. Washdown pads are provided for this purpose. Washing should be done with a fog nozzle, and personnel must be instructed not to direct the spray into the insulators. The asbestos sealing rings will become soaked with water and lose their resiliency upon drying. Also, they might not dry completely before the unit is returned to service.

Following the washing, begin repairs on the known faults. While this work is in progress, perform a detailed inspection of the other sections. Some items to be inspected in each area of the precipitator are as follows.

B.2.10.3 Upper Area

Insulators - Check for cracks or any signs of arc-over on both the lower and outer insulators. Replace broken or severely cracked insulators. Reseal insulators that show indications of significant air infiltration. If the sealing rings have deteriorated, these must be replaced. There should be some clearance between the inner and outer insulators.

Wire Masts - Check for loose bolts where the masts are connected to the upper high-voltage support frame. Tighten loose bolts. Exercise caution in tightening these because this can distort the mast, causing misalignment between the mast and the collecting plates. Cut out and remove any broken discharge wires accessible from this area. Keep records of wires that are removed. Loose or bowed wires can be tightened by crimping in the direction of gasflow. This must be done carefully so as not to distort or bend the mast arms.

High-Voltage Support Frame - Check for loose bolts and nuts and broken or failed springs; repair as needed.

Collection Plates - Check for loose nuts on plates and plate hanger eyebolts, broken or failed springs, and loose nuts on the plate rapper anvils. Check anvil striker plate for wear. Visually check plates for bowed or wavy areas and plate-to-wire misalignment.

General - Note any beams or frames that have slipped or tilted; broken welds; and the general condition of the internals, shell, access doors, and gaskets.

B.2.10.4 Lower Walkway Area

Alignment - Check alignment between the masts and the collection plates. Gross misalignment can usually be detected by visual observation. Questionable areas should be checked with a rule or gauge. Note any out-of-tolerance spacing. Also check the horizontal distance between the center mast bracing frame and the edge of the plates. Note any burned areas resulting from arcing.

Correct the alignment to the tolerances noted in manufacturer's handbook.

Plates - Note any warped, buckled, or wavy areas. Check lower plate foot and guide to ensure that plates are hanging free. Note any missing bolts or rivets in the plate assembly.

Wire Masts - Inspect wire masts for broken, loose, or bowed wires. Cut and remove broken wires and tighten bowed or loose wires by crimping. Check for loose or missing bolts on the lower mast spacer frame. These bolts must not be tight but should be snug. Close checks of these and any repairs will require a scaffold board in the ash hoppers for access.

General - Note any broken welds; evidence of air infiltration leakage; baffle distortion; ash hopper condition; and the general condition of the internals, shell, access doors, and gaskets.

Ducts - Inspect inlet ducts; inlet distribution baffle half rounds; and outlet ducts for distortion, corrosion, leakage, and ash buildups.

B.2.11 Records

Maintain detailed records of all inspections and maintenance performed on fly ash collectors. Copies of reports or other applicable records should be available at the plant for review by state air pollution control representatives or others and should also be maintained in the central office files.

B.2.12 Conclusions

This example of a utility precipitator maintenance requirements sets forth concise and detailed instructions, emphasizing the components that need the greatest attention in order for an ESP to operate properly. If used properly, those recommended maintenance procedures can serve as an excellent supplement to the manufacturer's procedures, providing further guidelines for an ESP operator in solving operating difficulties.

APPENDIX C

EXAMPLE OPERATING HISTORY OF COLD-TYPE PRECIPITATORS

This section is a review of maintenance and operational problems a major U.S. utility has encountered with cold-type precipitators over a number of years. Their plants are well maintained, and extensive records are kept. The operation and maintenance problems they report are a typical example of what could be expected at other power plants utilizing precipitators and operating under similar conditions.

In assessment of equipment operability, the best information concerning operation and maintenance of precipitators most likely will come from utilities with well-maintained plants, such as the one discussed in this section. Utilities with moderately or poorly maintained plants probably do not keep comprehensive records, and many problems may not be recognized or reported.

C.1 INTRODUCTION

This utility began the change from mechanical collectors to ESP's on new plant construction in the late 1950's. Further retrofitting of ESP's on existing units was made in 1967 and subsequent years.

Sixteen different types of ESP's serve 51 generating units, ranging in capacity from 60 to 1300 MW. These ESP's are supplied by five manufacturers, four domestic and one a domestic subsidiary of a foreign manufacturer. Coal comes from eastern and midwestern sources. Sulfur contents of the eastern coal range from 0.5 to 3.0 percent; sulfur content of the midwestern coal ranges from 3.0 to 5.0 percent. Each type of coal imposes special problems for ESP performance and reliability.

C.2 RELIABILITY AND MAINTENANCE EXPERIENCE

Very few of this utility's precipitator installations have demonstrated the expected reliability or maintenance cost. Major problem areas affecting reliability and maintenance involve (1) physical features of the collector design, (2) ash removal problems, (3) operating conditions such as gas temperature and coal sulfur, and (4) operating and maintenance practices.

All plants equipped with precipitators maintain operating and maintenance logs, which provide information relating to electrical operating conditions, ash removal operations, maintenance activities, faulty conditions, and sectional outage times. From these records, periodic summaries of precipitator operation are prepared for management review. These summaries contain various indices of precipitator reliability, including a precipitator availability factor defined as the ratio of the average bus section hours of operation to the hours of unit operation.

Figure C-1 shows the average availability record for all precipitators for a recent year of operation. The overall weighted average availability for this period was 92.6 percent. Only 6 of the 37 units in service during this period had 100 percent precipitator service availability. Four of these 6 units were 60-MW standby units, which operated only for short periods of time. The other two units with 100 percent availability were in the 150-MW class.

The principal cause of unavailability of precipitator bus sections was grounding of the high-voltage electrode systems resulting from malfunctions of the ash removal system and excessive ash accumulations on the electrodes. These problems accounted for 50 percent of the total bus section unavailability. The second most serious cause of bus section unavailability was discharge wire failures, which accounted for 36.5 percent of the unavailability. All other fault conditions such as failures of controls, switchgear, transformer rectifiers, and support insulators accounted for the balance, or 13.5 percent of the unavailability.

C.2.1 Ash Removal Problems

Failure to maintain adequate evacuation of the collector ash hoppers can lead not only to collector malfunction but

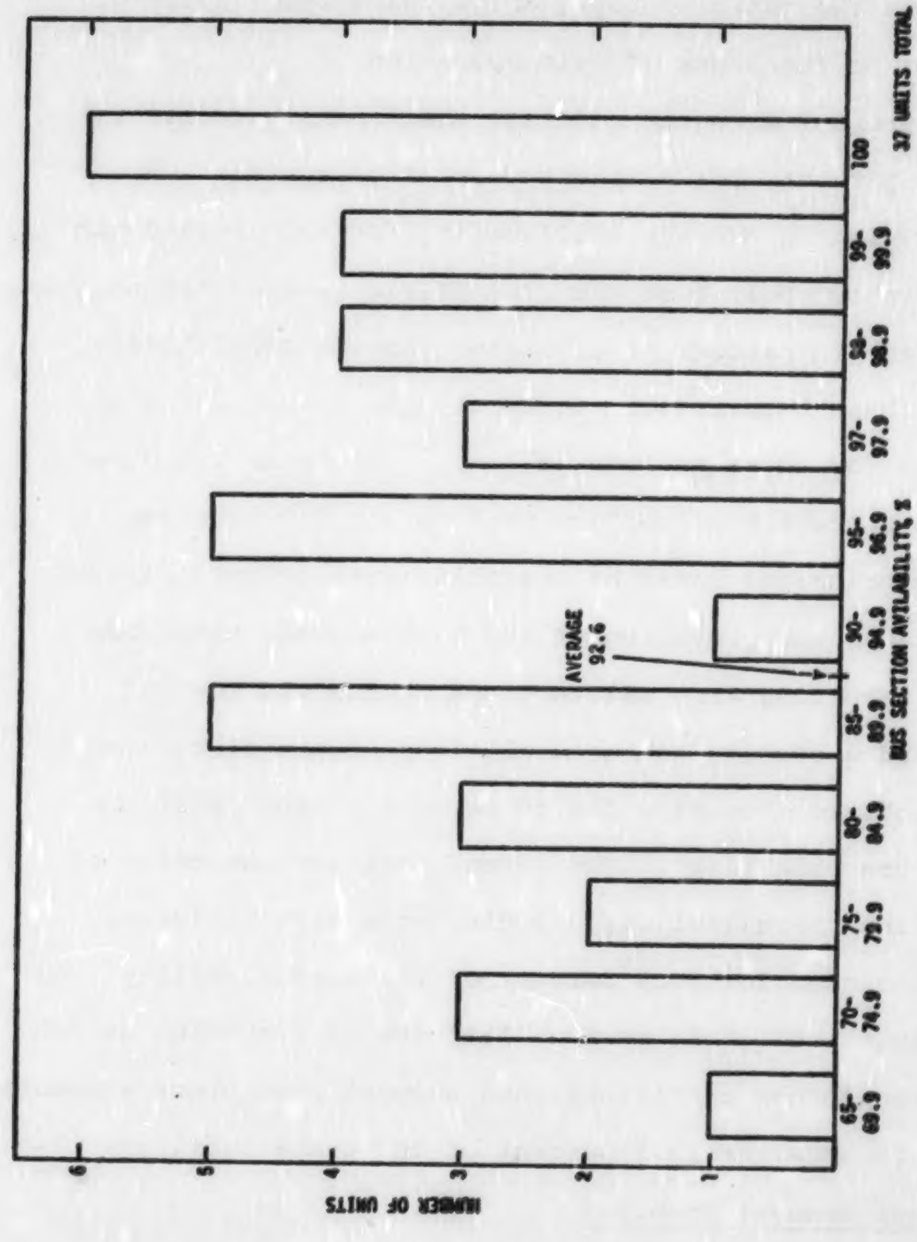


Figure C-1. Precipitator availability.

also to possible wire burning, formation of ash clinker, distortion of the high-voltage frames, and misalignment of collecting plates. Most ash removal problems result from insufficient capacity and flexibility of the ash removal and disposal systems. Other contributing factors are operation of low gas temperatures in combination with high-sulfur coal, inadequate hopper insulation, substantially higher quantities of ash in recent coal receipts, and less-than-desirable operating and maintenance practice.

Most of this utility's precipitators are equipped with sequentially operated dry ash removal systems. These systems have proved acceptably reliable when they are designed, operated, and maintained properly. For satisfactory operation, the precipitator hopper ash removal and disposal systems should be completely divorced from other refuse handling systems and should be of adequate capacity and arrangement to permit evacuation of each ash hopper often enough to prevent any appreciable accumulation in the hoppers. Unsatisfactory operation and maintenance of ash water pumps, water jet nozzles, vacuum connections, and sequencing controls can lead to loss of ash removal efficiency and to possible precipitator malfunction.

C.2.2 Discharge Wire Failure

The impact of wire failures on precipitator availability is a function not only of the frequency of failures, but also of the degree of sectionalization and the difficulty of removing failed wires from the precipitator during unit operation. Most precipitators do not have suitable isolation dampers to permit safe internal access while the boiler is in operation; therefore, only broken wires that can be reached from access hatches can be removed during unit operation. The attachment designs for some types of discharge wires require unit shutdown to make replacements; some attachments, however, are simple loops or hooks, which permit removal of broken wires during operation of some units.

The incidence of wire breakage varies from essentially zero on some collectors to several failures a day on other collectors. The most severe case of wire failures occurred on collectors serving cyclone furnace boilers burning coal with about 4 percent sulfur and operating with about 150°C (300°F) exit-gas temperature. The wire failures, which occur immediately below the top hanger hook and corona shield, are characterized by a progressive thinning of the wire until failure occurs. This condition became pronounced after about the first year of operation and led to the ultimate failure or replacement of nearly all wires.

Figure C-2 shows the frequency rate of wire failures on this installation for two operating periods during the second year of collector operation. These collectors have also undergone widespread failure of collecting plate support members, which were fabricated of carbon steel rather than the low-alloy, corrosion-resistant steel that was specified. The collector manufacturer attributes all of these problems to low gas temperature and high-sulfur coal, although operating conditions are very close to the specified design conditions. The total maintenance cost on these collectors for the first 3 years of operation was 25 percent of the purchase cost of the collectors. This is substantially higher than the acceptable annual cost of 1.5 percent suggested by one manufacturer.

Wire failures on other classes of precipitators occur at a frequency of about 0.3 percent a year; nevertheless, even this rate of failure can seriously impair collector availability on units that do not permit removal of broken wires during unit operation and on collectors of low sectionalization.

C.2.4 Transformer-Rectifier Failures

Power set failures occur at an annual average frequency rate of about 0.6 percent of the total number of sets installed and contribute a small fraction of total collector

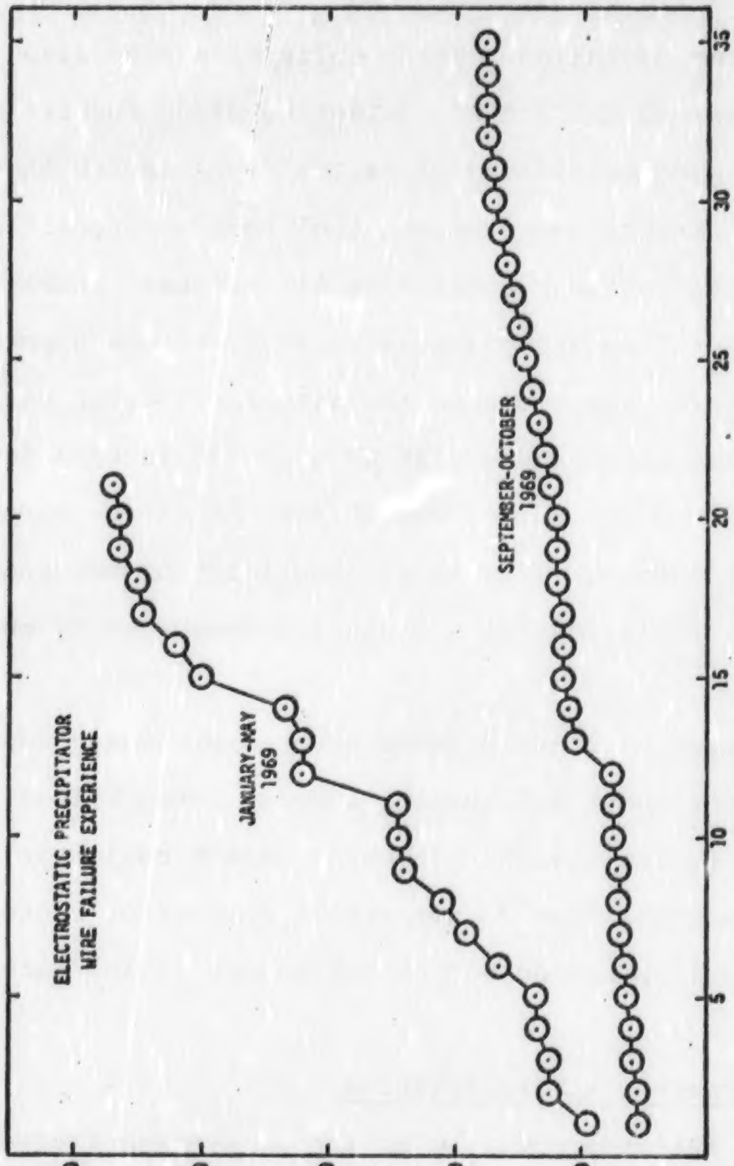


Figure C-2. Number of successive bus section failures.

unavailability. Most failures involved insulation breakdown, arcing between internal high-voltage switch contacts, and contamination of the insulating fluid.

One spare 700-mA power set is maintained as an emergency replacement for about 300 sets ranging in size from 400 to 1400 mA. Some large collector installations present problems in the removal of power supplies, but recent installations incorporate original design provisions for handling power sets.

C.2.5 Support Insulator Failures

High-voltage electode system support insulators of the cylindrical-tub type show a high rate of failure (about 5 percent a year) on installations operating with low gas temperature and high-sulfur coal. This type of insulator is subject to excessive fouling and to arc-over. Most insulator failures involve fine hairline surface cracking and not complete physical collapse. Insulator fouling and cracking reduce effective voltage levels and collector performance but rarely completely decommission a bus section.

C.2.6 Rapper and Vibrator Problems

Inadequacies of design, installation, operation, and maintenance of rappers and vibrators can lead to excessive dust accumulations on the electrodes, impaired performance, and possible grounding of the high-voltage system. A frequent trouble source is binding of the collecting plate rapper or vibrator rods at the points of roof penetration. This trouble is commonly neglected and may lead to ineffectual rapping. Pneumatic impact rappers installed on two of the collectors have the highest maintenance cost and the poorest reliability of all types. Severe misalignment has occurred on one type of collector in which the collecting plate assemblies are supported by the rapper rods.

C.2.7 Miscellaneous Items

Other common problems adversely affecting performance and reliability are overheating and failure of automatic control components and breakers, mechanical instability of high-voltage electrode systems, oscillation of wires, misalignment of wires and plates, infiltration of air, bypass of dust through inactive zones, and reentrainment of dust from hoppers. Precipitators that follow mechanical collectors are sometimes erroneously charged with poor performance as a result of air leakage and impaired efficiency of the mechanical collectors.

C.3.8 Conclusions

The unsatisfactory performance of some of this utility's early collectors resulted from inadequate definition of the requirements with respect to the range of operating conditions and also from the marginal sizing of collectors for the specified operating conditions. Recent specifications more realistically define the expected operating conditions and contain minimum acceptable sizing parameters and other inducements for contractors to provide conservatively designed precipitators.

Unfavorable reliability experience of some precipitator installations has resulted mainly from shortcomings of ash removal systems and excessive failures of discharge wires. Adverse operating conditions of coal sulfur content and gas temperature also contribute to poor reliability.

The emphasis of this utility on performance and reliability problems is not meant to suggest that electrostatic precipitators are not satisfactory for control of fly ash emissions. The utility officials state that successful installations are economically attainable by realistic definition of the requirements, proper design, and adequate operation and maintenance.